Forestry

H. G. CHAMPION
Professor of Forestry in the University of Oxford

Geoffrey Cumberlege
OXFORD UNIVERSITY PRESS
LONDON NEW YORK TORONTO
1954

First published in 1954

Printed in Great Britain by The Riverside Press, Edinburgh

PREFACE

In the following account I have attempted without going into technicalities to give a comprehensive but simple survey of my subject for those who feel some interest in it and wish to obtain a clearer idea of the part forests and forestry play in the general picture of human activities and welfare. The book was more or less deliberately drafted right away from forests and reference works, after three months touring in India where I had had opportunities of reviewing the progress of the past fifteen years in a country where the manifold role of forests and forestry were better understood than anywhere else in the Commonwealth, thanks largely to the vision of certain administrators of nearly a century ago.

Western Europe has unquestionably led the world in applying protection and management to forests in the general interest. Action was mainly consequent on experience of shortages, and it is unfortunately true that other countries have mostly failed to take advantage of the knowledge available to them until they too in turn have been faced with actual or imminent shortages. This history has perhaps led to the placing of undue stress on the importance of production of timber and wood fuel and to delay in recognition of the very vital role of forests in protecting soil and water supplies, in providing shelter to man and beast and crops, and in holding up unstable hillsides or fixing sandhills liable to move with the wind and bury good land. This protective action of a forest cover, which in no way reduces its productive value, is today receiving ever

increasing recognition so that one may venture the prediction that the time will come when it will be considered the primary contribution of the forest to human welfare.

Although the attempt has been made to describe what the forester does in the forests for which he is responsible, it has been my aim to keep technical details down to a minimum, and similarly for statistical information, though I have included examples drawn from all parts of the world where I thought they would be of interest or of help in indicating scale or relative importance. The whole subject has thus been approached from the general point of view with the exception of the last chapter dealing with forestry in the United Kingdom.

It will be appreciated that this book has not been written for those who are already familiar with the subject, but for the layman who wants to know more about it. Forest management is a subject which has long been neglected by the administrators and ignored by the general public, but it is gradually coming into its own in this overcrowded world as an important branch of land use affecting every one of us. My object will have been attained if the following chapters make some contribution towards a wider understanding of the significance of forestry and so bring increased support to the forester in the execution of his task.

H. G. C.

1953

CONTENTS

	PREFACE	v
I.	FORESTS AND TREES	1
II.	THE STRUCTURE OF FORESTS	26
III.	FOREST PRODUCTS	38
IV.	THE HISTORY OF FOREST CLEARANCE	50
V.	FOREST INFLUENCES	59
VI.	FOREST CONSERVATION AND PROTECTION	71
VII.	FOREST DEVELOPMENT AND INDUSTRY	100
VIII.	SILVICULTURE: NATURAL REGENERATION	118
IX.	ARTIFICIAL REGENERATION	127
X.	TENDING AND SILVICULTURAL SYSTEMS	146
XI.	GROWTH OF CROPS: MENSURATION AND MANAGEMENT: FOREST ECONOMICS	156
XII.	RECLAMATION AND AFFORESTATION	172
XIII.	FOREST POLICY AND LAW: RESEARCH AND EDUCATION	183
XIV.	FORESTRY IN THE UNITED KINGDOM	195
	CONCLUSION	213
	BIBLIOGRAPHY	217
	INDEX	227

Chapter I

FORESTS AND TREES

It seems desirable to begin any account of Forests and Forestry by defining these terms. Actually there seems to be some doubt about their precise derivation, though this is most usually stated to be from the Latin word *foris* meaning outside, the reference being to the village fence or boundary. If we accept this derivation as correct, the implication is that originally the word 'forest' covered practically all uncultivated or untended land. Such land would most ordinarily have carried tree growth of some sort, but would also include much that we would now probably term scrub, brush, or wasteland.

Nowadays a forest is usually thought of as a fairly extensive stretch of land covered with rather tall and dense tree growth. A forest tends to be contrasted with a 'wood' which is thought of as an area of moderate extent under tree growth that is relatively open and frequently broken by small gaps and glades. There is however no hard and fast line between a forest and a wood, though there is a tendency at least in technical literature to restrict the word 'forest' to the denser more or less continuous tree growth, and reserve 'woodland' for tree growth in which the crowns of the trees are frequently not in contact with those of their neighbours and may stand well apart.

There are many other words of rather indefinite meaning in common use in English speaking countries covering part or all of the significance of 'forest' and

'wood'. Thus we have *copse*, which originally meant tree growth that had been cut back or 'coppiced'; *hurst*, found in many place names, the modern German equivalent of which, *horst*, is now used in a technical sense as implying a group of trees; and *scrub* implying inferior open woodland. The Indian word *jungle* has been adopted into the language to cover the whole range of tree and shrub growth with a suggestion of wildness, whilst the word *bush* is similarly used in Australia and throughout Africa—sometimes with a differentiation into *high bush* for forest, and *low bush* for woodland and scrub.

It must however be kept in mind that the word forest has also come to have a special meaning in law; in this case 'forest' means any area of land, together with the growth on it, which has been declared to be forest under a legal enactment, normally a Forest Act or Ordinance. This meaning is in present day use in the case of the New Forest, which includes very extensive open heathlands as well as even cultivated and residential land. It may be noted too that many of the 'deer forests' of our hills are largely devoid of tree growth. In the following chapters, the word forest will ordinarily cover all woody vegetation, including 'woodland', but the latter term may occasionally be used where it is necessary to exclude the closed forest.

Turning next to the term 'Forestry' itself, a definition recently adopted by one of the leading authorities describes it as 'the theory and practice of the constitution and management of forests and the utilization of their products'. An alternative is 'the scientific management of forests for the continuous production of goods and services'. Each of these two attempts brings out a point missed by the other as will become

apparent in the account that will be given of the subject, and the following combination may be suggested—'the theory and practice of the management of forests, including their creation when necessary, for the continuous provision of produce and services'.

Distribution of Forests. The geographical distribution of forests over the land surface of the world, and the reasons that determine whether a given piece of land shall carry forest growth or some other type of vegetation such as grassland or heather moor, next calls for examination. It emerges at once that forest has evidently covered by far the greater portion of the world's surface, though human activities have very greatly reduced the area actually occupied by it at the moment. It is today difficult in many parts of the world to be certain what the original vegetation may have been, but this will not affect the conclusion that woody growth was the dominant vegetation almost universally except where pronounced desert, arctic or extreme alpine conditions prevail. This seems to be correct more or less regardless of soil conditions, as woody plants can colonize and persist on almost any stable soil, in crevices in rocks, and on lands subject to repeated flooding including tidal estuaries. The one exception to this general prevalence of forest is the occurrence of extensive grasslands in a few regions such as the prairies of N. America, the pampas of S. America, and the steppes of S.E. Russia and adjoining Asiatic territories. In Africa there are also extensive grasslands, but the scattered trees suggest that tree growth may have been much more extensive before human activities largely eliminated it. If now the climatic conditions experienced in these grassland tracts are examined, it is found that they are characterized by a

low total rainfall occurring mainly as light falls in the growing season; a similar rainfall in cool months is associated with woody types of vegetation in which grasses, though present, are not the chief component.

It would thus appear that forests of one sort or another formerly covered all regions except those just specified, and it is estimated that they must have occupied about two-thirds of the total land surface, which is some thirty-two billion acres. Actually very large areas have been denuded of their original growth by the impact, direct or indirect, of human activities, so that on an approximate estimate, only rather over one-quarter, some nine billion acres, still carries forest and woodland. As might be expected from the zonal distribution of climates, the forest cover is concentrated in three zones, the equatorial and the north and south temperate belts, separated by the dry zones of the sub-tropical latitudes very roughly following 25° N. and S. Latitude. Polar land surfaces are of course devoid of forest, but it may be noted that the region on which some of the lowest temperatures (e.g. $-70°$ C.) have been recorded lie in the forest belt of Siberia. There the summer, short as it is, is adequate for tree growth which can survive the frozen soil and rigours of the long winter. Owing to the unequal distribution of land and sea, the south temperate forest zone is very poorly developed, in strong contrast with the north temperate belt which is of the greatest importance in the world today.

When individual regions or countries are considered, it is found that very wide variations occur in the percentage of land covered with forest, according to climate, topography and history, so that the recorded range varies from 1 or 2 per cent. up to nearly 90 per

cent. as shown in the table overleaf. When considering these figures, however, it must be understood that it is not yet possible to get national statistics on a sufficiently uniform basis for strict comparison to be possible. Once again the wide differences in interpretation of the descriptive term 'forest' complicate the issue, even when it has been agreed to adopt uniform definitions. The reasons for the exceptionally low figures may be either unfavourable climatic conditions, as for Australia, or a long history of forest denudation, as in Britain.

Definition of Tree. So far no attempt has been made to define a tree, although a forest is thought of as composed of trees. What is it that differentiates trees from other plant forms and how has this difference originated? The contrast is really between long-lived plants that become woody, and short-lived plants which do not, viz.: herbs, grasses, mosses, etc. As long as a plant lives and functions it must grow, and with increased size comes the necessity for stiffening and support. This is not the place to go into the details of plant growth, but woody plants have discovered, as it were, how to reinforce the relatively feeble supporting framework of the non-woody plant, and so provide for increasing bulk and weight. At least two solutions to the problem have been evolved by the higher plants, one by the palms and bamboos and their allies (representing the Monocotyledons), and the other by the rest of the trees, the conifers and the Dicotyledons or broad-leaved trees. In the palm, radial growth is not possible, so that a mature stem of any one kind of palm is more or less of a standard thickness determined early in the life of the individual, though growth in height may continue to 60 ft. or more; reinforcement

Country.	Total Forest Area. Thousands of acres.	Total Area. Thousands of acres.	Percentage under Forest.	Population. Millions.	Productive Forest Area. Thousands of acres.	Area of Productive Forest per head. Acres.	Source.
EUROPE—							
United Kingdom	3,448	56,203	6·1	49·6	3,448	0·07	1947 Census.
France	27,067	135,937	19·9	41·0	27,067	0·66	
Germany	31,135	116,137	26·8	66·5	31,135	0·47	*Forestry and Forest Products*, F.A.O. 1946.
Switzerland	2,224	9,884	22·5	4·5	1,977	0·44	Ditto.
Spain	12,108	124,291	9·7	25·6	12,108	0·47	
Netherlands	618	7,979	7·7	9·4	618	0·07	
Finland	53,522	75,489	70·9	3·9	51,150	13·12	
ASIA—							
Syria	927	45,862	2·0	3·0	247	0·08	
AFRICA—							
Union of S. Africa	9,170	302,426	3·0	11·4	2,036	0·18	
Kenya	3,467	140,625	2·5	4·1	1,364	0·33	
Gold Coast	39,679	58,768	67·5	3·6	22,340	6·21	
AUSTRALASIA—							
N. Borneo	41,599	48,286	86·2	1·0	12,160	12·16	
Australia	76,416	1,903,698	4·0	7·5	50,045	6·67	
AMERICA—							
Canada	826,201	2,215,709	37·3	12·3	520,383	42·31	
U.S.A. (excl. Alaska)	624,099	1,905,027	32·8	141·2	474,007	3·36	
British Guiana	44,799	51,518	87·0	0·4	34,559	86·40	
WORLD	9,019,397	32,621,401	27·6	2,166·6	..	[4·16]	Ditto. Last figure is gross acreage.

Statistics extracted from *Forest Resources of the World*, Food and Agriculture Organisation, U.N. 1948 except where otherwise indicated.

is possible and occurs, but not increase of thickness. The broad-leaved trees and conifers, on the contrary, add a fresh zone of woody growth every year as long as they live.

To be considered a tree by the botanist or forester, a woody plant must also have a single erect main axis, at least in its lower parts; if the stem breaks up into many branches from near the ground, it will be described, not as a tree but as a shrub, more or less regardless of size. There is of course a third important category of woody plants which are unable to support themselves but scramble or climb over the adjacent larger shrubs or trees. These are the woody climbers or 'lianes' which are usually found as a constituent of any forest community, and become very numerous and conspicuous in the tropics.

It is interesting to note that not all families of plants include trees. There are some families in which woody representatives are rare or non-existent and others in which this position holds for herbaceous forms. Thus the *Ranunculaceae* or buttercup family are almost exclusively herbaceous, whilst the *Compositae* or daisy family include a vast number of herbs and only a few trees, mostly small. On the other hand, the *Cupuliferae* or oak family and the *Magnoliaceae* contain no herbs. The *Leguminosae* or pea family provides a good example of a family which is equally well represented by trees, climbers, shrubs, and herbs. It is perhaps of interest to note that some groups of plants now represented by small non-woody or hardly woody forms are descended from an ancestry including large trees—this is the case with the horsetails and the insignificant club mosses which are the living representatives of the groups *Equisetales* and *Lycopodiales*, the fossil remains

of which contribute largely to our coal deposits. Many instances could be quoted in which the tree habit has been lost in the course of evolutionary descent; this probably often holds for the rare herbaceous members of a typically woody family, e.g. *Verbenaceae* which includes the teak and many other trees. There are also instances of tree forms which have adopted the climbing habit with appropriate modifications in anatomical structure, and even some in which the tree form appears again to have been reached by the climber, its story being still revealed by its internal structure, for example, species of *Dalbergia* among the *Leguminosae*.

Height Attained. Accepting the tree as a woody plant with a self-supporting axis, the conditions under which it grows and the problems with which it has to contend may be considered. A fuller picture of these may be obtained if the dimensions attained by trees are kept in mind. Dealing first with height growth, there are several kinds of trees which on good soil can attain a height of 300 ft., though claims for a height of 400 ft. have not been substantiated, at least for any living tree. The outstanding examples are the sequoias of western N. America, and some of the eucalypts of Australia, notably *Sequoia gigantea*, the Big Tree, and *Eucalyptus regnans*, the Mountain Ash, for which heights of 364 ft. and 347 ft. respectively can be accepted as definitely established. It may also be noted that Douglas fir reaches 220 ft. in its own home—even 417 ft. has been claimed—and has been recorded as attaining 168 ft. in this country. The English oak has been reported to run up to 130 ft., beech to 135 ft. and Scots pine to 128 ft., and the tallest trees in Britain are probably a Douglas fir at Powis Castle and a Silver fir at Inveraray,

both 168 ft. Incidentally tropical woody climbers have been found attaining a length of 750 ft.

The two major problems presented by height growth of this order are the raising of water and other food supplies to the active crown, and efficient resistance against the force of wind tending to break off the trunk or uproot the tree. The former problem is even now not entirely satisfactorily explained; obviously as for the ordinary pump, no simple continuous column lifting mechanism would suffice to raise water more than about 30 ft. The modern view that the suction power of the leaves (osmotic pressure of the leaf cells) working through sap-filled elongated tissue elements (vessels and tracheids) so constructed as to minimize the risks of rupture of the minute water columns and to localize them when they occur, would seem adequate in view of the very high cohesive power of water molecules. The water shortage consequent on any breakdown of this mechanism is rapidly reflected in the dying-back of the top extremities of the tree, giving a condition known as 'stag-headedness'.

Form of Bole. Turning to the stiffening of the trunk to carry the growing crown and avoid breakage by wind, detailed studies have shown that the typical shape of tree stems is mechanically well adapted to provide maximum support and resistance to pressure with minimum bulk. Most trees, particularly those growing in the open and so under more exposed conditions, have a moderate basal swelling near the ground which naturally gives a buttressing effect. This tendency is greatly developed in tropical regions, many trees being provided with an extensive buttressing system extending many feet up the stem, even to 20 ft. or more. Sometimes these supporting structures are of the

nature of flying buttresses, the best known example being the true mangroves (*Rhizophora*). It must be noted that when trees are growing close together in a forest, they give one another a considerable measure of mutual protection and support; under these conditions the form of the stem is still adapted to the conditions under which it has developed, but may prove inadequate if the tree is isolated by the felling of its neighbours. The more cylindrical form associated with close growth is highly desirable when timber production is a major consideration, whereas the more conical low branching form is expected and suitable in trees growing under hedgerow and park conditions.

Heartwood. The ring or layer of woody tissue formed each year under the bark over the whole of the broad-leaved and coniferous trees by the sheath of growing tissue (the cambium) remains active for the conduction and storage of water and dissolved substances for a period of years as *sapwood* but is ultimately changed in several ways and dies to form the *heartwood*, still functioning to support the ever expanding crown but no longer for conduction. The changes often include a darkening in colour—elm and larch—though not necessarily—beech, ash and spruce—and very generally involve improvement in properties as timber, above all in durability. In many species, the heartwood is highly resistant to insect attack and decay whilst the sapwood is quickly destroyed. The number of annual rings that are fully functional (as tested by ringing experiments) may be only two or three but is typically more, and the change to heartwood usually takes ten to twenty-five years.

Girth Records. Although the majority of kinds of trees appear to have certain limits of size which they

rarely exceed, there would seem to be no theoretical limit to growth in girth and volume, and very large dimensions are attained, particularly by trees the timber of which is naturally resistant to decay, e.g. the true cedars. As might perhaps be expected, the sequoias and eucalypts again hold the records. Some living examples of the Big Tree (*Sequoia gigantea*) have a girth of over 100 ft. (measured at the standard height of 4½ ft. above the ground), whilst the corresponding figure for eucalypts is about 85 ft. The records for some of our common English trees are given at 30 ft. for oak (a tree standing in Sherwood Forest), 31¾ ft. for beech (a tree at Windsor) and 16 ft. for Scots pine. A figure of about 180 ft. is frequently quoted for a sweet chestnut —the Tree of the Hundred Horsemen—growing in Italy, but this figure (already recorded in 1780) refers to the hollow shell of a stump which now only carries a few peripheral shoots. The interesting case of the *baobab* of C. Africa for which a girth of 90 ft. has been recorded is also noteworthy, but here the bole is barrel-shaped, very different from that of normal trees. Many tropical trees are impossible to measure for girth owing to the very extensive development of the buttress outgrowths already mentioned.

Tree Volume. It may be of interest to note the upper limits of timber volume which have been found in single stems, though the figures will perhaps convey little to the layman. From what has been said already, it would be expected that the maximum would be found in the sequoias and eucalypts and this is true. The highest authentic figure of which I am aware is 50,000 cu. ft. for *Sequoia gigantea.* This is about ten times what we can find on a well-stocked acre of spruce. The corresponding green weight of wood might be

about 1,400 tons. It is perhaps worthy of mention that 31,400 cu. ft. have been measured in a single bole of the New Zealand kauri (*Agathis australis*), a tree which develops an exceptionally fine unbranched cylindrical bole running up to 100 ft. long before breaking into the spreading crown.

Age of Trees. Just as with girth and volume, so also is the age attainable by some trees unlimited except by the hazards of storm, lightning and fire. Age is not easily determined for old standing trees even for those kinds which have recognizable annual rings of growth. Among felled trees, ages from ring counts up to 4,000 have been recorded for the sequoias and the cedar of Lebanon, but the ages of 3,000 for olive and 1,500 for oak all appear to include estimates for hollow centres. As an example from the tropics, a record of 680 years may be quoted for teak, which unlike most tropical trees has easily discernible annual rings. It may be taken that there are still living trees of approximately these ages. In England, the yew is attributed with extreme longevity, but authentic records are few, and the record may well be held by the famous tree of Fortingal which was over 50 ft. in girth in 1769 and so on average rates of growth may have started life 1,500 years ago. The oldest living oak may perhaps be put at about 600 years and Scots pine perhaps 300 years. Humboldt's estimate of 5,150 years for a large boabab is quite inacceptable, as also the extreme figures sometimes quoted for the sacred banyan (*Ficus bengalensis*) of the East.

Life History of the Tree. The life history of the tree must next be briefly reviewed. Most trees bear both male and female organs on the one individual and indeed in a single flower, but it is fairly common to

find some degree of segregation, thus all conifers, oak, beech, and birch have male and female flowers, whilst some trees have at once male, female and bisexual flowers (maples). When male and female flowers are separate, they are usually borne in separate clusters or inflorescences, as in the conifers and hazel. Less commonly there are separate male and female trees as in the willows, the Lombardy poplar, many palms and some members of the fig family (e.g. the important *iroko* tree of tropical Africa), but it is rarely possible to recognize which is which on the purely vegetative characters. Sometimes a tendency to this segregation may be present though the majority of trees are bisexual, as in the ash.

Pollination. The methods of pollination of trees make a very interesting study which cannot be dealt with in detail here. The majority of the trees of the temperate regions bear relatively inconspicuous flowers and are largely dependent on the wind for pollination. This may perhaps be linked with the relatively short growing season and the poverty of insect and other animal life at the critical time, and it may further be related to the prevalence of certain families such as the *Cupuliferae* in which inconspicuous flowers and wind pollination are characteristic. Exceptions do however occur, for instance many of the magnolias of temperate forests have strikingly large and conspicuous flowers and the willows are largely insect pollinated.

In warm regions, trees tend to have more conspicuous flowers, or conspicuous masses of small flowers. The vast majority appear to be adapted to pollination by flying insects, bees and flies and perhaps less frequently, moths and butterflies. In contrast with smaller plants, there is a marked development of pollination by larger

animals, particularly birds. Bird pollination is typically associated with large red flowers frequently massed and so visible from a distance. Many instances occur in the *Leguminosae* and *Bignoniaceae*. Some species in both families are reported to be pollinated by bats.

Precise information is scanty from forest trees to indicate the extent to which cross-pollination is necessary for the setting of seed, but the pollen and stigmas of a tree frequently mature at different times. Advantage is taken of this fact to ensure crossing where hybrids are sought, as between European and Japanese larch. In larches, the female organs are receptive before the pollen is shed, so a stock of European larch which sheds its pollen early, is grown in mixture with the Japanese larch, which is thus likely to be cross pollinated.

Seed Crops. After pollination the fruits and seed form on the trees, sometimes very rapidly, sometimes very slowly; in many oaks and pines the seeds mature only in the year after pollination. A point of considerable practical importance in forestry is the fact that there is usually a great variation in seed production from year to year, and it is rather exceptional that one can count on at least a fairly good crop every year, as one can with birch and sycamore. In many cases, it is not a question of failure of seed to set and mature owing to unfavourable weather conditions, but of failure to flower, and this in turn is only sometimes theoretically explicable as due to lack of reserve materials consequent on a heavy crop in the preceding year. Ash and Scots pine tend to give ample seed every two or three years and some at least can be collected most years, but oak and beech are notorious for the long intervals that sometimes occur between the good years

which mostly follow a drought year. In the Chilterns, there were no good beech mast crops between 1922 and 1944. There is a suggestion here of a relation to the sun spot cycle, which the previous good mast year of 1912 tends to support.

The tropics provide us with a much more remarkable phenomenon, still quite inexplicable, viz. the periodic gregarious flowering of certain bamboos at intervals of twenty or thirty years or even longer. When the time comes, a wave of flowering sweeps across a tract of country and within two or three years practically every plant flowers, fruits and dies, and seed may be quite unobtainable until the next cycle. Cuttings taken from a plant and grown elsewhere are recorded as flowering in the same year as the parent stock. The same phenomenon of gregarious seeding is met with in undershrubs of the Acanthaceous genus *Strobilanthes* with much shorter cycles of three to twelve years. Some palms such as the talipot only flower once at a considerable age and then die, but flowering is not at a definite age or gregarious.

Seed Dispersal. The fruits of trees vary enormously in form and size and the next biological problem for consideration is the method of distribution from the parent tree to a suitable place for further development. As compared with the smaller types of plant, two main differences, both of which might be expected, are found to occur: (*a*) the much greater prevalence of wind dispersal, and (*b*) the rarity of some of the devices which lead to distribution by terrestrial animals, viz. sticky and burr mechanisms. Noteworthy among wind-dispersed seed are the minute seed produced in large quantities by such trees as the birch, the rhododendrons, and many trees of tropical forests. The very

light hairy wind-borne seed of the willows and poplars must also be mentioned. As in the case of most minute seed, only a relatively small proportion is capable of germination, but the enormous quantities produced ensure the best chance of at least some seedlings becoming established wherever a suitable site is available.

Winged papery seeds even up to two inches across are found in trees of the family *Bignoniaceae*, to which the bean tree (*Catalpa*) belongs, and plumed seeds comparable to those characteristic of fruits of the *Compositae* are usual in some tropical families. It is characteristic of trees possessing such wind-borne seed that they tend to be the first to establish themselves on any newly bared soil, for example landslips, abandoned cultivation and volcanic deposits. Most of the conifers have winged seed likely to drift some distance before reaching the ground. At the other extreme, there are trees with large heavy seed which fall to the ground below the parent tree where most of them have but small chances of development. Here, dispersal is dependent on removal by ground-feeding animals, by birds, or by water running over the surface. They are accordingly usually palatable to animals, or float. In many cases the fruits may be swallowed by the animals, the seeds being passed through the alimentary tract and subsequently voided on a new site where they may become established; or in the case of ruminants, cast up after the digestion of the outer layers. A not uncommon occurrence with heavy seed is a modified development of the winged form, so that the fruits which tend to be broken from the tree only when a strong wind is blowing are at least drifted beyond the immediate shadow of the parent tree; the maples provide an example of this and the fruits of many of

the *Leguminosae* and other trees of the tropics show variations on the same plan.

The part played by arboreal animals in the distribution of tree seeds is well known through the instance of the activities of squirrels in collecting and hiding the seed of beech, etc. Some of these caches escape being eaten subsequently and so may germinate. It is probable that in the tropics, both squirrels and monkeys play an important part in distributing edible seeds, despite the quantities that they must consume and destroy. It seems generally agreed that in this country jays are responsible for the introduction of the scattered oak, beech and chestnut plants which early find their way into plantation areas of other species, and parrots do the same in warmer countries.

Seed dispersal by water is perhaps commoner than is thought, particularly in trees of riversides and estuaries. The seed may be of various forms, but it usually floats and some is ultimately deposited on new gravel, or sand and mud banks where it germinates, and if not washed away by subsequent floods, will develop into a forest and protect the new land from erosion. The seed of some trees seem to be dependent on wind carriage to reach the water in the first place, for example *Dalbergia sissoo* in India, but more usually the seed or fruits are relatively large and drop straight into water from overhanging branches or are washed into the stream by water running over the surface of the ground during heavy rain. The well-known instance of the mangroves should also be mentioned; here the seed germinates on the parent tree and the seedling already provided with a long root drops like a javelin into the soft mud beneath. Explosive mechanisms are perhaps not as common as with herbaceous

plants but are well known in such examples as *Hura crepitans*, the Sand-box tree of tropical America, and several of the *Hamamelidaceae* (witch-hazel family).

Germination. When the seeds of trees have reached the ground, they may germinate at once if conditions are favourable for this development, or they may lie dormant for a varying length of time. In temperate regions, it is perhaps most usual for seeds to ripen and be dispersed at the end of the season of vegetative activity, and to remain dormant until stimulated by a rise of temperature in the spring. It has been shown in some instances that a dormant period of this kind is an essential preliminary to further development. Longevity in seeds appears to be an adaptation to severe climatic conditions and it is exceptionally developed in the *Leguminosae* and in certain pines in which the unopened cones may become deeply embedded in the bark till a fire opens them up and releases the still viable seed.

In most cases, it is preferable if not essential for the seed to be lightly covered with soil for it to germinate and become established; deep burying both reduces and delays germination. Very commonly the root develops more rapidly than the shoot, the oak providing a good example of this, so that on careful examination it will be found that a quite small seedling has a disproportionately long root which has penetrated deeply enough into the soil to ensure an adequate water supply to the developing shoot. This may be vital in climates subject to prolonged dry periods. If the roots are unable to penetrate deeply enough before such a dry period sets in, what appears to be a most promising carpet of seedlings may all die out. The seed-leaves or *cotyledons* may be used for food storage remaining in the seed coat or fruit as in oak, or may develop into

functional green leaves, often of unusual shape, as in beech, ash and conifers.

Establishment. The period between the germination of the seed and the seedling stage at which the young plant is relatively secure against the ordinary hazards of climate, etc., is referred to as the period of 'establishment', and the forester cannot count on seedling growth for a new crop until it has passed through this stage. The hazards to which it is exposed besides drought, include frost, excessive shade, insects, fungi, browsing animals, and often fire. To maintain the existing position, it may be assumed that each existing tree can only ultimately make room for a single similar individual, and yet the quantity of seeds and seedlings produced may be prodigious. Thus a mature tree of pine (*P. longifolia* in India) was estimated to produce an average annual crop of ten thousand viable seeds, so that a full crop of fifty trees on an acre would be potentially capable of giving two million seedlings, or one hundred per square yard, and to continue to do this every year for fifty years or more. The wastage is thus enormous, but apparently necessary to ensure the survival of the species.

Water Requirements. The seeds of the majority of trees are of fair size and provided with enough food reserves to give the resultant seedling a start in life before it can absorb and elaborate the food materials it needs for further growth. Before these reserves are exhausted, it will need to obtain from the soil a supply of water containing dissolved nutrients and it will also need light as a source of energy. Except in the case of tree seedlings establishing themselves on open ground, the seedling will normally have to start life on soil already intensively occupied by existing vegetation,

and only such light will reach it as can filter through the leaves of trees and other plants above it. Water is perhaps the most vital requirement. Trees on the whole are better adapted to conditions of extreme drought than most other higher plants. In dry regions, it is characteristic of tree roots that they can penetrate to extreme depths in search of adequate moisture. Penetration to a depth of 100 ft. or more has been recorded. Herbaceous vegetation being much less deep rooted, is dependent on the moisture of the surface layer of the soil and so tends to develop only when rain falls. On the other hand, many trees are structurally adapted to exercise extreme economy of water, particularly during the driest part of the year, but they can continue to obtain the necessary minimum from the deeper soil levels. At the opposite extreme, many trees are adapted to grow with their roots more or less permanently in water, though this water must contain at least some dissolved oxygen for them to function physiologically. Many trees growing in the estuaries of the bigger rivers are adapted to tolerate water of varying degrees of salinity, and frequently have to withstand periodic submergence in brackish water. Attempts have been made to determine how much water is necessary for the continued growth of trees. Without going into details, it may be stated that the indications are that a tree crop in temperate regions may take up the equivalent of from two inches (Scots pine) to twelve inches (beech) of rainfall. One worker in Java in the tropics has concluded that tree crops there similarly use forty inches to one hundred and twenty inches of rainfall in the formation of about seven tons of wood annually.

Mineral Requirements. As regards requirements for

mineral nutrients, it has been established that the requirements of trees tend to be relatively low, so that most soils contain enough of the essentials to permit of fairly normal growth. Deficiency of lime, however, definitely affects tree growth in some cases, and a striking instance of pathological conditions associated with deficiency in zinc has been established with *Pinus radiata* in Australia. On the other hand, excess of lime in the soil is associated with an unhealthy condition reflected in the yellowing of the leaves, as often to be seen in beech on shallow chalk soils. Soils excessively rich in humic matter tend to be deficient in phosphorus and nitrogen, as has been demonstrated on the raw humus and peaty soils of the northern conifer forests. Here additions of phosphatic and nitrogenous manures may result in improved growth; deficiency of potassium can also sometimes be demonstrated. Apart from the cases just mentioned, trees do not generally appear to suffer from nitrogen deficiency, but it is noticeable how important a position the *Leguminosae* hold in the forests of most parts of the world, ranging from the semi-deserts (where Acacias often predominate) to luxuriant tropical forests, and one is tempted to relate this to the presence of nitrogen fixing bacteria in the nodules on their roots. It is moreover interesting to note that one tropical tree which shows good development on sterile coastal sands, viz. *Casuarina* (beefwood), is provided with exceptionally strongly developed nodules of a similar type. Alders also have nitrogen fixing bacteria in conspicuous nodules on their roots. Incidentally, it is curious that not a few shrubs and small trees of the undergrowth of tropical forests have similar nitrogen fixing bacteria in their leaves, recognizable as dark green dots.

Mycorrhiza. Before leaving the question of root activities, mention must be made of the presence on the root tips of a great many trees of sheaths of fungal hyphae. The significance of this association—known as mycorrhiza—is still not fully understood, but it is well established that it goes with good growth and it appears that the fungus facilitates the nitrogen nutrition of the tree especially in humic soils.

A general feature of the mineral nutrition of tree growth is that a considerable part of the minerals absorbed from the soil is rapidly returned to the soil in the fallen leaves, etc. This phenomenon has been expressed by saying that the forest, particularly in the tropics, grows largely on the products of its own decay, and so may flourish even on poor and shallow soils. It may be noted that a well-grown beech tree may contain about 12 lb. of mineral matter as determined from the percentage of ash when samples are ignited. The amount returned annually to the soil through the two tons of litter falling on an acre of forest is about 180 lb., including some 50 lb. of lime, 10 lb. of potash, and 12 lb. of phosphorus. The breakdown of vegetable detritus restoring these minerals to circulation is too long a story to be discussed here, but it may be noted that small animals, insects, bacteria and fungi all play their part.

Light Requirements. As regards light requirements, considerable variation is again met with. In a general way, all trees require full light for optimum development, but some are much more tolerant of shade than others. How large a proportion of the incident light falling on the top of a forest is reflected or absorbed is shown by the fact that the light intensity at ground level in a dense forest may be even less than 1 per cent.

of its original value. The actual form and structure of leaves may vary according to whether they have developed in or are adapted to sunlight or shade, e.g. in beech, and much more markedly in *Eucalyptus*; once a leaf is formed it cannot subsequently adapt itself to changed light conditions which must result in death or serious loss in efficiency. It must be noted that poor seedling development under shady conditions which might easily be ascribed to lack of light has repeatedly been found to be primarily due to lack of moisture consequent on the root competition of the shading vegetation. This can be demonstrated by isolating a naturally occurring group of seedlings by digging a trench around them, thereby severing the competing roots; markedly better development will then take place in comparison with the untrenched area.

Evergreen and Deciduous Habit. The leaves of trees only remain functional for a limited period of time after which they are shed and replaced by new ones. In temperate regions, the majority of trees are leafless during the winter months whilst in the seasonally moist hotter climates, they are similarly 'deciduous' during the dry season. There is presumably some gain to the tree from this action of throwing off its old leaves and this is generally taken to be a reduction of water loss at a time when water is difficult to replace owing to the dryness of the soil, or low physiological activity of roots in cold soil. It has to be noted that damage by snow and wind is reduced in the leafless condition, and that a good deal of mineral substance is returned to the soil, ultimately for re-use.

If there is no completely leafless period, the new flush of foliage may occur very soon after leaf-fall so that though the tree may be classed as an 'evergreen', the

life of a leaf barely exceeds twelve months, but a much longer life is possible, up to several years, as is readily checked to occur on most conifers where the growth of successive years is easily recognized. A striking feature in the tropics is that the new flush of foliage may be coloured brilliantly red or pink for a short time, perhaps providing a protection for the developing green colour against injuriously intense light. The familiar autumn colouring of the temperate zone deciduous forest is apparently only incidental to the breakdown of the colouring matters present.

Quite a number of trees shed short branches with the leaves, the swamp cypress, *Taxodium*, being a good example, and a few cut off and drop some of their smaller side branches in the sapling stage to form a clean bole—foresters could wish this was commoner. It is perhaps not generally recognized that when pine trees shed their needles in small clusters of two, three, or five, they are really shedding dwarf shoots.

Genetics. It is only of recent years that the importance has been realized of the application to forestry of the principles of the science of genetics worked out on animals and herbaceous plants and extensively applied in agriculture and horticulture. The first step was the recognition that a given tree species such as Scots pine differed appreciably in different parts of its natural range, some types being markedly superior in form from the timber production point of view, and others markedly inferior with crooked boles and heavy branching. It was also noted long ago that these characters were liable, if not indeed likely, to be transmitted through the seed when sown in a new locality. In general, seed brought from a place with very different climatic conditions was likely to give

poor results and this was widely experienced when trade in seed began to replace local collection, particularly with Scots pine. Over the past fifty years comparative experiments have been widely made with seed of most of the more commonly planted trees collected from a wide range of localities, abundantly establishing the importance of paying attention to this matter. The evidence to date is that the safest source of seed is the best crops found in the same region and at much the same altitude as the site in which it is to be used. It is interesting to note that with European larch in Britain, seed from good Scottish plantations has given at least as good results as the best freshly imported seed from the natural homes of the species: it will be appreciated that these plantations represent the results of an earlier selection by elimination of the less satisfactory, though some 'acclimatization' factor may be involved. Later work has shown that many characteristics of importance to the forester are transmitted to a varying extent through the seed, particularly when present in both parents as may be assured by controlled pollination. As was to be expected, trees are just like any other plants in genetic constitution and behaviour and all the techniques of selective breeding and crossing can be applied with similar results though trees are naturally usually more difficult to handle and the work may take longer. A well-known example is that of the extra vigour which is sometimes found in first generation crosses, and has turned up in marked degree with the cross between European and Japanese larch and in crosses between European and American poplars. Big advances in forest genetics are likely to be a feature of the near future.

Chapter II

THE STRUCTURE OF FORESTS

THE foregoing review of the life history of the individual tree leads on to an examination of the life of the complex communities of plants, particularly the trees themselves, which together form a forest. Such examination immediately reveals the wide diversity and complexity which occurs in nature. Except in artificial plantations, it is most unusual to find a forest composed of a single kind of tree, though occasionally instances do occur naturally on sites with some exceptionally pronounced characteristic such as dryness, wetness or coldness. Even in these instances, there will always be a mixture of subordinate growth forming an understorey or ground cover.

It is difficult today, particularly in the long settled regions of Europe, to find forests which can be considered to have been but little influenced in their composition and structure by human activities. It is obviously a matter of speculation what the original forest was like. On the whole it would seem that even when growing under fairly uniform conditions, it must have varied considerably from place to place though older and larger trees would have been relatively more numerous and the total plant cover denser and more varied than we now find in most semi-natural woods.

Perhaps the most usual condition is for a forest to be composed in the main of a relatively small number of kinds of trees of generally similar form. This is the case with the extensive broad-leaved and coniferous forests

of the north temperate zone, and similarly with most of the forests of the drier sub-tropics and tropics. When however the more luxuriant largely evergreen forests of the wet tropics are examined, it is found that one of their main characteristics is their markedly heterogeneous composition, such that no one kind of tree forms more than a quite small proportion, say 5 per cent. of the total number of the larger trees. Not only is this the position among the larger and taller trees forming what is known as the dominant canopy of the forest, but it holds equally for the subordinate vegetation. Under less favourable conditions, there may be very little tree and shrub growth beneath the dominant canopy, but as conditions for growth become more and more favourable, so the variety and complexity of the forest community grows. Frequently there is a second order of trees that are reasonably well developed but are apparently unable to secure and maintain a place in the dominant canopy so that they form a second canopy layer. The trees forming this second storey are, as one might expect, rather more tolerant of shade and adapted in various other ways to their subordinate position; in Britain, we frequently find holly and yew occupying this position in our deciduous forests. There may be further tree layers before we come to a typically tall shrubby one about 15 ft. or 20 ft. high (e.g. hazel), below which again may come low shrubs, and ultimately below them, either bare ground or a layer of herbs, ferns and mosses.

Additional complexity is added by two further forms of plant life, viz. climbers and epiphytes. Climbers, which in the forest are mostly woody, take advantage of the presence of other trees, using them as a support over which to climb with the aid of various devices up

to better light higher in the canopy. Here they may spread over the crowns of the trees, robbing them of light and often breaking their crowns by sheer weight. Epiphytes are plants adapted to establish themselves directly on the trees from seed which falls on the trunk or branches. Some epiphytes, for example many figs, subsequently send down their own roots to the soil, but the majority have to make do with the very limited amounts of mineral nutrients which are available to them from decaying organic matter, dust, etc., and with the moisture from the periodic rainfall which is often stored by special devices—or even with only atmospheric humidity. Many orchids and ferns are particularly well adapted to these exceptional conditions.

In addition to this differentiation into canopy layers, the structure and appearance of a forest is considerably influenced by the varying forms and characteristics of the constituent trees and smaller plants. Reference has already been made to the fact that it is characteristic of some kinds of trees (termed *deciduous*) to shed their leaves in an unfavourable season, either a cold or a dry one. This phenomenon will obviously greatly affect the appearance of the forest and its biological activities. Frequently the top canopy may thus be deciduous whilst the lower storey or storeys may be evergreen, as in the case quoted of holly and yew under oak and beech. Another feature calling for mention is the prevalent size of the leaves, the leaflets of a compound leaf counting as leaves for this purpose. A given leaf size is commonly related to certain conditions of life in the forest; thus leaves in dry forests are typically small, as in desert *Acacia* scrub, whilst really big leaves are only common in wet tropical forest particularly in the undergrowth (cf. banana

leaves 6 ft. by 1 ft.). The presence of conifers also gives a marked impress, and similarly for the palms which are most strongly developed in the New World, and the tree ferns of moist temperate forests.

Competition. Beyond these mainly static aspects, the forest must be viewed as a living complex, and as for each individual component, the processes of birth, growth and death are constantly in operation, whether any attempt is being made to direct them or not. The forest itself has its life history just like the individual tree. The first point that attracts attention is that within the forest there is constantly a double struggle going on, a struggle against the unfavourable factors of the environment, and a struggle between species and individuals, one with another, for the available growing space, both above and below ground. It must be admitted at once that very little is known about the underground struggle. We know that different components of the forest may spread their root systems at differing depths in the soil, some at a deeper level, some more superficially. We know that they take up different proportions of the available minerals in the soil and, as already noted, they compete for available moisture when it is in short supply. It can also be demonstrated that every constituent species, and every forest as a whole, exerts an influence on the soil itself, an influence which may sometimes be far reaching, not only through what is taken from the soil, but also through what is added to it by the deposition of fallen leaves, twigs, bark fragments, etc. It is thus to be expected that soil conditions are always changing if only gradually, being suitable at one time for the establishment of seedlings of a given species, but not at another time when they will better suit a different

species. It is common that a species is unable to regenerate on the site it actually occupies, whilst sections of peat deposits reveal evidence of the fluctuations of vegetation that have occurred on the sites they occupy. There is a suggestion that some plants at least may excrete into the soil substances toxic to possible competitors. It may also be noted at this juncture that soil processes at the surface are considerably influenced by the amount of light, heat and moisture reaching the surface, these factors being primarily determined by the nature and density of the leafy canopy.

The conditions and processes going on above the surface of the ground are much easier to study, and a considerable amount of information has been collected both from direct observation and from experimental work. The struggle for growing space proves to be a very severe one indeed, the more so the better the general conditions for plant growth. This can perhaps be exemplified most simply for a single species by reference to the fall in the number of trees that an acre of forest land can support in healthy condition as a young tree crop progresses towards maturity. At the start there may be perhaps ten or more seedlings per square yard or fifty thousand to the acre. By the time they have reached the height of about 10 ft. this number will have fallen or should have been reduced to about five thousand; at a height of 20 ft. the number might be around one thousand, after which it steadily falls off to about one hundred or even less trees at maturity. Even if we have many kinds of trees, in several storeys and of all sizes and ages mixed up, the same general principle will apply that between germination and maturity there is always an enormous reduction in numbers. Under natural or semi-natural conditions,

this reduction is brought about by the failure of the majority of individuals to survive under the intense competition that is always in progress. If conditions in a mixture of species are at all unsuited to any one of them, it may be completely eliminated. Thus fifty years ago it was locally a fairly common practice in England to plant spruce, larch and pine in alternate rows. If crops started this way are examined today, it will frequently be found that the pine has completely disappeared through inability to compete successfully against the larch in parts of the area, and often the spruce elsewhere. It will be seen in a later chapter that forestry techniques for bringing about the results most desired under the objects of management pay particular attention to regulating this competition.

Climax Forest. Returning to the life history of natural vegetation, it may be recalled that in a general way the type of forest found on a given site appears to be determined by the local climate and soil, usually modified to a varying extent by human interference. But it is exceptional for conditions to be static, and the question arises as to whether a stable end-point can be reached. There is some difference of opinion among botanists on this matter. The suggestion has been made that the nature of the soil itself is mainly determined by climatic factors, even where the parent material from which it is formed differs widely. This would leave climate as the preponderant factor in determining the nature of the vegetation that a site will carry, provided sufficient time is allowed for equilibrium to be reached. This hypothetical equilibrium or end-point is termed a 'climax', in this case for any given type or climate, the 'climatic climax'. Other authorities, even when conceding the general theory of a single climax,

stress that the time taken to reach it may be long, even in relation to the rate of climatic change, and so they find it necessary or convenient to recognize several climaxes within a single climatic type depending on soil (edaphic) conditions. Thus whereas a pond in an oak wood may in the course of time silt up, and after carrying a succession of types of vegetation, may finish up as the climax oak/beech wood, a rocky hillock in the same area might remain indefinitely unable to accumulate a sufficient depth of soil to carry the general climatic climax.

It must be noted that in many parts of the world the effects of human activities have been so far-reaching that we cannot with any certainty say what the climatic climax may have been, and we must agree that it might well take centuries to reach it once again. Even in forests which have been little disturbed, the concept meets with difficulties, in view of the observation that types of forest which appear to be widely spread and of climax status, appear to generate conditions unfavourable to their own regeneration and perpetuation. This is for example the case with the conifers of the northern hemisphere. A view which is gaining wide acceptance is that forests may consist of a mosaic of patches in different phases of a general life history, so that whereas change is always in progress, the overall picture, the real climax, remains the same. However this may be, foresters have found that it is helpful to them to know as much as possible about these tendencies and in which direction they are working, for it is then easier to apply a guiding hand to give events a turn in a desired direction, and to know when one must adopt more drastic measures to stem the ecological 'tide'.

Classification of Forests. Many attempts have been made to classify the various forms of forest met with in the different parts of a country and the world at large. The botanist would prefer to classify on the basis of the form and structure of the forests as he finds them, but as might be expected from what has already been said, these classifications tend to be based primarily on climate with soil as the second factor. The chief difficulty encountered is the complexity of the climate itself, for it is built up of many factors each exerting its own influence on the vegetation. The chief of these factors are temperature and temperature extremes, and rainfall and its seasonal distribution. Many investigators have tried to derive a single climate index which would, for example, accurately define the climatic and geographical limits between coniferous forest and arctic scrub. In single instances such as the one quoted, fairly satisfactory results have been obtained, but the method breaks down when general application is attempted. It may be noted in passing that some climatologists start at the other end, using the vegetation as an index of integrated climate, and so falling into line with the biologist's approach.

Despite these difficulties, there are certain broad types of vegetation clearly related to the main climatic factors, that can be recognized whenever they occur. Thus there is a marked general similarity in many respects between the forests associated in different countries with tropical temperatures and a high, well-distributed rainfall; mangrove forests have much in common wherever they are encountered; so too have the winter deciduous forests and coniferous forests of the northern hemisphere generally. The one complication that must be borne in mind is that the available

raw materials, as it were, out of which a forest can be constructed in any given part of the world, will be determined by geology, evolutionary history, and species migration; thus there are no cacti in the Old World to occupy the semi-deserts there, nor are there pines native to Australia, or eucalypts outside Australasia. Migration, or changed climate coupled with marked adaptibility, must account for the unexpected occurrence in a community of a form or habit typical of quite different conditions. For example, a cactus-like *Euphorbia* occurs in the wet evergreen forests of the Andaman Islands, though cactoid euphorbias are characteristic of very dry climates and soils, and specially adapted to the conditions prevailing in them.

Human Influences. Reference has already been made to the very far-reaching effects of human influences, direct or indirect, on the forest. In a general way, it will be found that these influences tend to produce a forest which resembles more that which would be expected under soil and climatic conditions less favourable to plant growth than direct observation shows to exist. Such forests appear more open, drier, and less varied than they should. It is worth examining this process somewhat more closely. Men have of course cleared great areas of land, particularly on the more fertile alluvial lands or gently undulating uplands, for agricultural purposes. The fact that further large areas have been cleared of forest for the sake of the timber, where the land was either not wanted or not suitable to agriculture, is generally known. But the extent to which human populations with their associated live-stock have altered the appearance of the residual forest, is not appreciated by the layman. The main factors bringing about these changes have been

the gradual but unceasing cutting down of the trees for timber and firewood; grazing, which has a very detrimental effect on forest regeneration and seedling establishment because stock consume or destroy by trampling such seedlings as might otherwise be able to establish themselves on the exposed and hardened soil; and burning, which has been done for a variety of reasons such as removing cover for carnivora, obtaining a fresh early growth of new grass, and for extending the grazing area by driving back the forest. In a general way, the damper the type of forest, the more sensitive are its constituent species to damage by fire, and the more luxuriant the grass which will probably replace the tree growth, and this luxuriance will increase the intensity of the inevitably recurrent fires. Reference should also be made to a very prevalent practice of primitive agriculturalists, which is to cut down most or all of the growth on an area of forest and run a fire through it, preparatory to purely temporary cultivation of food crops. These people usually move to a new area every year or two, and have destroyed the original forest over many thousands of square miles in the tropics. The same practice was quite common in Europe at one time.

Artificial Forests. In concluding this chapter, account may be taken of the artificial tree crops which form the bulk of the forest area of our own country, and indeed of western Europe generally. There are also very large areas of forest plantations in other countries, notably S. Africa and New Zealand. When the essential needs for timber and wood fuel have come to be appreciated as a result of shortages, the first step has usually been the introduction of some measure of protection and regeneration of the residual woodlands of

natural origin, with a view to ensuring their perpetuation through regeneration and improved production of material of the kinds and size most in demand. This is the history of the State forests of France and Germany, but in many places, conspicuous among them our own country, most of the forests were so degraded by misuse that it became essential to recreate them by planting or sowing. Sometimes this was done with one or more of the species already present, as in the mainly oak forests of the Forest of Dean and New Forest. In other cases, more quickly growing species introduced from abroad were preferred, as in the many plantations of larch, Douglas fir and spruce. Often, the conditions of soil and climate offered to these exotics were very different from those prevailing in their original homes, so that at least local maladjustment would have to be expected. Apart from the species used, the structure of these artificial forests is likewise very different from that of the natural forest. Instead of the natural variety and complexity, the young crop has been started with trees all of the same kind (or perhaps two or three kinds only) evenly spaced over the area, all of precisely the same age. Such diversity as arises later is derived from the chance invasion of locally occurring plants with suitable seed dispersal mechanisms and colonizing powers. Like agricultural crops, these artificial tree crops are particularly prone to attack by disease and insects, but it must be remembered that, again as with agriculture, direct preventive or remedial measures may be more easily and economically applied than in the irregular natural forests. It has also to be noted that the effects of the standing crop on the soil will be more pronounced in these plantations, and if unfavourable may create

conditions unsuitable for a second crop or even for the later stages of the first. It will be seen later that forestry practice has to compromise between economically preferable and possibly biologically more desirable choices.

Wood has always been used extensively for making agricultural implements. Even today, steel ploughshares have not everywhere ousted the wooden plough, whilst rakes, rollers and many other implements, as well as the handles of most, are still usually made of wood as the best material for the purpose. Wood is still extensively used, if not quite as much as in earlier days, for making utensils of many kinds for agricultural and domestic use, thus bowls, troughs and churns. Another important use, particularly in the earlier stages of human social evolution, has been for weapons—bows formerly and gunstocks today. For each of these different purposes, in any given region, there will be certain kinds of timber which are much more sought after than any others available—yew for bows, ash for tool-handles, sycamore for rollers, birch for turnery, chestnut for split fencing, beech for chair legs, elm for weather boarding, and so on.

Wood fuel. In some places, even more important than timber for any of the purposes just mentioned, is wood as fuel for cooking and heating. It is usually only when the original woody vegetation has been so completely eliminated that there is no supply of wood fuel accessible to the human population, that its vital importance comes to be recognized. In several densely populated parts of the world, this stage has been reached, and the predominantly agricultural population has been forced to use agricultural waste as the only available alternative. First the vegetable waste, such as cornstalks, is used, and soon the animal waste, such as the dung of the domestic stock. But these waste materials are essential for the maintenance of the humus content and fertility of the soil, and to use them as fuel inevitably leads to soil deterioration, diminishing

crops, and finally to the abandonment of the exhausted land. It seems certain that over large tracts of the world an ensured supply of wood fuel reasonably close at hand will continue to be essential for a long time yet, if indeed, not always.

Bamboos. The bamboos form an important group of forest plants which, without being trees, yield material which can be put with a minimum of preparation to most of the purposes for which timber is used. They are really giant woody grasses and belong to a considerable number of species although superficially they are all generally similar except in size. Being monocotyledons, their structure is very different from that of the majority of timber trees which are dicotyledons or conifers. This structure is such as to provide a most excellent combination of strength with lightness, the woody tissues being in the form of a hollow cylinder with strong cross partitions at intervals along it; the sections are much used for water buckets, etc. Bamboos have also been found to be quite suitable for the manufacture of paper, and are in fact being exploited for this purpose on an increasingly large scale, notably in India.

Wood as a Chemical Raw Material. Wood is mainly composed of the two chemical substances cellulose and lignin, and by suitable treatments it can be separated into these constituents. The cellulose is nowadays a most important material for a considerable variety of purposes, the most familiar of these being paper making. The annual consumption of wood for the manufacture of pulp today stands at the astonishing figure of 4¾ billion cu. ft. This figure means that in one country or another, about ten million acres of forest are being cleared every year for pulp alone, or it may

be viewed as the total annual growth of at least one hundred million acres of pulpwood forest. This demand is steadily and rapidly increasing, despite possible alternative materials such as agricultural waste which is also largely composed of cellulose, for example straw or sugar cane waste. Cellulose is itself the raw material from which the rayon type of artificial textiles is made. The rayon industry absorbed well over one million tons of wood in 1950, and this figure is estimated to reach two million by 1955, the amount of rayon used being almost identical with that of wool.

Moreover cellulose is one of a wide group of chemical substances closely related to the sugars, and can by suitable processes actually be converted into sugars. These sugars in turn can be fermented to give industrial alcohol, and much alcohol for use as fuel, etc. is derived from this source. The yeast organisms which bring about the fermentation synthesize vegetable proteins in the process, and this leads us to the beginning of another range of products, for we have now reached the second main type of food material essential to animal life, and it has been so used in times of stress, at least for feeding stock. It is not suggested that it is at present an economic proposition to convert wood waste into cattle feed, but it can be done if the need is great enough, as was the case in the Scandinavian countries during the second world war. It may further be noted that in Finland, for example, the greater part of the national supply of baker's yeast is obtained as a by-product from the wood-pulp mills. Hitherto the lignin part of wood has proved less amenable for conversion into materials for which a demand at present exists. It might be thought that it should be possible to obtain from it a range of products similar to those obtained

from coal, but this has not so far been done. In the meantime, the lignin is used to some extent in the preparation of plastics and other materials.

Food Supplies. Besides timber and fuel, the trees of the forest yield a very wide range of other useful materials so numerous and diverse that only a limited number of outstanding examples can be mentioned. Firstly, there are edible products among the fruits, flowers and leaves which are regularly collected by people living in or near the forests, although it is of course true that the most important kinds tend to become cultivated crops raised in the village fields. A still wider range of forest plants provide fodder for domestic stock; in fact, as we shall see in a later chapter, this may lead to serious damage and even destruction of the forest. In many parts of the world, practically the only meat available to the people is what can be obtained by hunting, and the remaining animal life has nearly always to be sought in the forest which alone provides the shelter and protection essential to its continued existence.

Medicines. Akin to the foodstuffs are products used for medicinal purposes. Some of these such as quinine have also been taken out of the forest and raised in plantations, which curiously enough are mostly in countries where the wild plant does not occur naturally; others, such as the seeds yielding an important remedy for leprosy (chalmugra oil), are still collected from wild plants. A similar type of products is the extensive range of fish poisons, etc. which may be most important to communities still dependent on hunting and fishing.

Fibres. Agricultural communities require fibre for a great variety of purposes and the majority of their

supply is obtained from forest plants, mainly climbers; they are needed for bow-strings, fishing nets, snares, in house construction, and for many field and domestic uses. Some of them may be woven into materials to be used for clothing, etc.

Gums, Resins, etc. Another group of forest products includes the gums, resins and latexes produced by certain kinds of trees and climbers. These substances are usually exuded if the tree is cut and their biological function seems to be to repel attacks by animals and to seal wounds against entry of disease organisms. Many of these materials are not only used in the local economy but have found a place on world markets; thus gum arabic, the many kinds of damars (particularly from the Malayan region), the resin from pines which on steam distillation can be separated into rosin, used for varnishes, insulating materials, etc. and turpentine, a most valuable solvent. Outstanding in this class is rubber; as with other products already mentioned, the growing world demand resulted in the displacement of the collection from the wild trees by extensive artificial plantations on forest sites cleared for the purpose, but during the second world war a concerted drive had to be organized to collect as much as possible from the naturally occurring trees in the forest.

Tannin, Dyes, etc. Tanning materials are very largely forest products, such as the bark of oak, chestnut, wattle and mangrove, wood extracts such as the valuable *quebracho* of S. America, and fruits such as myrobolans. In S. Africa, well over half a million acres of plantations of tan-bark wattles have been established, mostly by private owners. To conclude this illustrative list, mention may be made of vegetable dyes obtained from trees; perhaps the most notable example is provided

by the logwood of Central America which at one time provided the most important and valuable export of the region. Even today, several vegetable dyes are still being manufactured from forest trees and associated plants.

Fodder. The fact that the forest is the natural home of so many wild animals suggests the thought that it should also provide forage for domestic stock. From the earliest times, livestock have in fact been grazed in the forests adjoining the villages, particularly in the temperate zone and the seasonally moist tropics—in the wet tropical forest, the woody growth is too luxuriant to permit of the development of herbaceous ground vegetation suitable for cattle feed. In the more advanced countries, there has been a gradual change in favour of keeping cattle on the farms, at least part of their feed being grown as regular crops, but over all the under-developed regions, as well as locally elsewhere, forest grazing continues to be almost universal. Under certain conditions, it can be demonstrated that the forest can support regulated grazing without serious damage to its growth and maintainance, and there may be tracts where this will always continue to be the best form of land use. On the whole, however, it seems inevitable that with the passage of time, it will be recognized that forest grazing is usually good neither for the forest nor for the cattle.

From all these considerations, it will be appreciated how very dependent mankind has been, and still is, on the forest and its products for many of the essentials of life. Any acceptable standard of living calls for adequate housing and fuel supply; this dependence is most pronounced in the less developed parts of the world today, but it was the same in the more advanced

countries during their earlier history. Even with the rapid development of modern times, this condition will long persist in many parts of the world, so that measures for the maintenance of adequate areas of forest, suitably distributed, must remain one of the first essentials of land policy. This necessity refers to meeting immediate material requirements from the forest, quite apart from the at least equally important protective role of the forest which has yet to be discussed.

Turning now to the quantitative aspect of our requirements of wood from the forest, it may be asked, what is the average quantity needed annually per head of population, and what area of forest is necessary to provide this quantity in perpetuity? Actual requirements and existing forest conditions vary so greatly that it is impossible to give a reliable average figure. It is however possible to examine the present ranges of production and consumption as a basis for arriving at working figures. To take first current levels of consumption, statistics have been published by some countries, and collected by U.N. and other organizations, but difficulties arise from the fact that, except for timber for industry, a great deal of wood and other forest produce is taken for domestic use from small and large woods without any possibility of its being included in official records. This is particularly the case for wood fuel, and a more reliable basis would seem to be provided by special studies of actual consumption in representative examples. For what they are worth, the resultant data that are exemplified in the following table indicate that the total consumption of wood for all purposes as both timber and fuel ranges from about one cubic foot, where it is difficult to obtain as in India,

to 140 cu. ft. where it is still fairly easy to get and winter needs for heating are high as in Canada.

Naturally, wood-fuel consumption is greatly influenced by the climate and the availability of alternatives. Finland is credited with the greatest consumption per caput at 70 cu. ft. per annum. In England the

WOOD CONSUMPTION PER HEAD PER ANNUM

Country.	Total Consumption. Cubic feet roundwood.	Wood Fuel. Cubic feet roundwood.	Industrial Wood.	
			Cubic feet roundwood.	Sawn equivalent.
Nigeria	0·7	0·3	0·4	0·2
India	1·1	0·7	0·4	0·2
Kenya	4·2	2·1	2·1	1·3
U.K.	16·6	0·4	16·2	9·7
France	22·6	11·7	10·9	6·5
U.S.A.	73·4	12·3	61·1	36·7
Australia	75·6	37·1	38·5	23·1
Canada	142·6	59·0	83·7	50·2

consumption of wood fuel is negligible owing to the universal substitution of coal, gas and electricity, but only a century or two ago, wood was the standard fuel here also.

Turning to timber consumption, the data for sawn timber are fairly reliable, and show that the average consumption per head of population varies from under one cubic foot to about 10 cu. ft. for the industrialized countries with forests such as France and Germany. The figures for the United Kingdom and the U.S.A. are 10 and 37 cu. ft. respectively. It may be hazarded that the figure of 35 cu. ft. per head per year for wood in the round for timber and fuel combined may be taken

as the amount that should be made available generally, though in considering any country or region, an independent figure would have to be used.

How does this figure of 35 cu. ft. compare with the annual production of an acre of forest, properly managed or not so? There is plenty of reliable information as to the growth of managed forest which can be taken as a basis for estimates of possible production elsewhere. Thus the average production of a fully stocked acre of medium quality (II) oak forest covering the whole range of age, is about 40 cu. ft. per annum. A corresponding figure for beech is 60 cu. ft., whilst for conifers production is considerably higher, being 120 cu. ft. for spruce, and even 200 for Douglas fir. In formulating the national policy for the U.K., an average annual production on the relatively poor sites available for afforestation mainly with conifers has been put at 70 cu. ft. per acre. All these examples are taken from the temperate region where conditions on the whole are quite favourable for tree growth. Much lower figures must be expected for the less favourable conditions of the hotter drier countries, particularly where the forests are not adequately protected and managed. It would not seem over-cautious to put the estimate at 10 cu. ft. for the very extensive areas concerned. As regards the seasonally moist tropical forest, the few figures available for single species plantation crops are not greatly different from those quoted above, thus for teak and the sal of India about 120 and 100 cu. ft. respectively. Very high figures of production have been recorded for young plantations of tropical species in favourable forest climates, as high as even 500 cu. ft. per acre per annum, but at present the actual production of most wet tropical forests is

greatly reduced by the very low proportion of kinds of timber at present utilizable in such forest. Wood fuel is there in excess, but the figure for utilizable timber is usually at best at least no higher than given above for managed temperate forest and is usually much lower. To summarize, it would look as though from the point of produce required, there should be at least one acre of forest per head of population in all under-developed countries; in a later phase, when standards of living have risen, but skilled management has been applied, the need may come down to half this figure as an overall average, but will vary considerably according to the productivity of the forest area available. This conclusion should, however, never be allowed to obscure the fact that a much larger area of forest may often be necessary for protective purposes.

Chapter IV

THE HISTORY OF FOREST CLEARANCE

Clearing for Agriculture. In the earliest stage of human evolution, man was primarily a hunter, and merely one more animal largely dependent on the forest for food and shelter, living more or less in equilibrium with his environment. As he advanced to an agricultural phase, the forest or parts of it became an obstacle to the raising of herbaceous food crops and his attitude towards it underwent a change. From being the very source of his existence, it became an enemy to be fought back and if possible destroyed. Many factors must have been involved in the selection of the first sites to be used for agricultural crops, bearing in mind the risks from predatory animals, the range of fertility of soils, the density and vigour of forest growth, and the ease with which it could be cleared and prevented from re-invading, only primitive tools being available. It may be that there was an original preference for the open natural grasslands, but in view of the restricted and local occurrence of such land, the bulk of the needs must soon have been met from forest areas.

In England, our earliest extensive agricultural clearings appear to have been on the relatively dry limestone hills. It is probable that here as elsewhere, fire was extensively used to supplement the stone or bronze axe. Under the conditions that existed, grass would quickly extend as the tree cover was broken,

and the grassland could be burnt and so protected from recolonization by tree growth. It is noteworthy that one of the most characteristic trees of these areas, the beech, is thin barked, easily killed by girdling, and particularly sensitive to fire. At that time, the more fertile lowlands on deep alluvial soils were badly drained and very difficult to clear and keep clear. A similar history would seem to hold for most other parts of the world, the more luxuriant forests surviving longest for the very reason of their luxuriance, supplemented perhaps by their unhealthiness for human occupation. Land communication being difficult, many of the earlier settlements involving forest clearance have been along navigable water courses. As soon as cultivated crops began to be raised, they must have been subject to damage from raids by wild animals which could approach them unseen through the surrounding forest, as also could dangerous carnivores. The early cultivators had accordingly every reason for doing everything possible to push back the forest from the proximity of their fields.

Forest Grazing. Some primitive agriculture continues to this day without the help of domestic draught animals, as in those parts of Africa where owing to cattle disease they cannot be kept, and in many mountain districts in all continents. As a rule, however, domestic animals both for draught purposes and for food products have been associated with agricultural practice from the earliest times. Such livestock has normally been dependent for its fodder on the forest land adjoining the cultivation. Most draught animals prefer grass and herbage to the leaves of trees, i.e. grazing to browsing, and this has provided an additional incentive to their owners to reduce or eliminate tree

growth in favour of ground herbage. Axe and fire have everywhere been used for this purpose. There are some kinds of livestock, such as goats, buffaloes and camels, which are predominantly browsers, and these have been the cause of very widespread destruction of forest cover. Even the grass-eating kinds take to tree foliage at certain seasons and in times of grass scarcity. This in turn often leads graziers to the practice of lopping trees to provide the fodder, resulting in the worst cases in the destruction of any trees still surviving the other hazards. Account has also to be taken of the fact that some races and groups of people have developed on a pastoral as contrasted with an agricultural basis; this has usually happened in and around the natural grasslands and in the open grassy types of forest often referred to as savannas. These people with their flocks are often migratory, moving from place to place according to the season and available forage supply. Commonly for at least part of the year, they move into the more forested areas where they have been the cause of extensive forest destruction.

Forest Fires. Like the agriculturists, the graziers also are very prone to set fire to the ground vegetation for the sake of a flush of fresh grass, regardless of the effects on the remaining tree growth. There can today hardly be any part of the world where forest grazing has been extensively practised that has not been fundamentally altered by the annual or periodic firing that has prevailed, in some cases for centuries. Where hunting continues, fire is commonly used to concentrate the game and drive it towards the hunters.

Forests are liable to be set on fire in a number of ways besides those already mentioned. Farmers very ordinarily burn agricultural waste on their fields

without worrying whether the fire spreads into the adjoining forest; travellers and forest workers are equally negligent with regard to their camp fires, charcoal kilns, etc.; and honey collectors smoke out bees from hollow trees without bothering to extinguish the fire later. The worst recorded fires have nearly all originated in areas where industrial felling operations have been in progress so that an exceptional amount of dry inflammable material covered the ground. Outstanding instances are the Great Idaho fire of 1910 in the U.S.A. which swept over two million acres of forest, destroying timber of a value estimated at twenty million dollars and taking eighty-five lives; and the 1939 fire in Victoria, Australia, which burnt over five million acres of eucalyptus timber forest, destroying also sixty-seven sawmills and six hundred buildings.

'*Economic*' *Crops*. Very extensive forest clearances have been made over the last century for raising 'economic crops' such as coffee, tea, rubber, coconuts, cocoa and cinchona. The range of requirements of these crops is such that no good forest in the tropics from sea level up to 6,000 ft. altitude has been safe. The establishment of these plantations has almost invariably involved the clearing of the best forest land. In not a few cases, as best exemplified by coffee in S. India and Ceylon, many plantations have subsequently failed from disease, soil erosion, or other causes, and the land has been left denuded and unproductive; grass invasion has usually occurred and fire has then prevented the return of the forest. There are also some food crops raised mainly for distant markets that have led to similar destruction in both temperate and tropical regions, for example potatoes and pineapples. Methods of cultivation have frequently been such as to

lead to serious soil erosion and ultimate deterioration, sometimes to the extent of rendering the land completely unproductive. This destruction is unfortunately still going on in many parts of the world despite all the efforts of those who appreciate the seriousness of the losses involved. It has proved very difficult to secure public recognition of the need for preventive action in the matter.

Agricultural Land Needed. In a previous paragraph, an attempt was made to estimate the area of forest land necessary to meet the annual wood requirements. It may be of interest to see how this figure compares with the area required for actual food production. As far as the U.K. is concerned, it would appear that during the war years we succeeded in producing about one-third of our requirements from thirteen million acres of arable land, importing the remaining two-thirds. From this it would seem that on the average we each use the produce from one acre. In India, with a lower standard of living and lower production per acre, the arable acreage is given (1937–38) at 393 million acres for 388 million people, a considerable quantity of rice being imported. The number of livestock in relation to the human population may also be noted. In Britain we have roughly thirty million head of cattle of all kinds for a population of nearly fifty million. In India, where forest grazing is universal and cultivated fodder crops are an exception (practically limited to the N.W. of the country), there were in 1937, 210 million head of horned cattle.

Distant Markets. Local shortages of timber arose as soon as human populations increased, so that from very early times accessible forests had to meet not only local requirements but the demands from distant

markets. For many centuries, roads being absent or inadequate, timber was almost exclusively transported from the forest to these markets by water. This meant that forests easily accessible to floating streams were subjected to heavy fellings, often amounting to complete clearance in a short or longer period of years. The timber had of course to be of kinds that would float, and the richer the forests in suitable timber, the easier and the more profitable it was to work them. This situation concentrated the drain on the coniferous forests of the northern temperate zone. Timber rafts have been brought down the Rhine for many centuries, and the process continues both there and in the rivers emerging from the Himalayas, in the forests of Scandinavia and Canada, and in many other places. Gradually more modern methods taking a longer view have developed, and management for sustained yields is slowly being introduced. Unfortunately, these timber extraction operations have resulted in the wasteful destruction of a much larger area of forest than that actually exploited for human use. This has happened through the agency of fires spreading into the unworked forest as already described, and through insect epidemics. The presence of large quantities of felling refuse and damaged trees permits some of the most injurious insects which breed in such material to multiply excessively, and they then move in such large numbers into the unworked forest that they can attack and kill healthy trees which are relatively resistant under normal conditions. This may sometimes happen on a very large scale and examples will be given later.

Wood for Mining, Smelting, etc. Wood is also required in connection with other industries, particularly heavy industry. In southern England before coal was

extensively used there were innumerable forges in all forests where ironstone was available. In medieval times there were seventy such forges in the Forest of Dean alone, and the 'Hammer' Ponds associated with forging are still to be found dotted around the Sussex Weald. Large areas of forest were cleared in this way since little thought was given to the long term maintenance of supply, the only considerations being proximity, ease of working and cheapness. Similar instances could be quoted from other countries and for other minerals, for example copper in Sweden and Rhodesia. Apart from the wood required for the smelting operations, very large quantities are needed for lining and supporting the workings, etc. in the mines themselves. The enormous supplies of pit props needed for coal mining —about one cubic foot for every ton of coal—falls into this same category. The annual consumption of pit props in Britain is round about 95 million cu. ft. Serious inroads have also been made in many places to meet the need of a lime-burning industry, and the construction of railways has very usually involved reckless felling to supply the necessary wooden sleepers. An incidental form of damage to the forest is seen in the extensive injury and mortality due to fumes from smelting works; spectacular examples of this are to be seen in the copper belt of the U.S.A. Even in this country, smoke and acid fumes make tree growth very difficult in many places, for example in the narrow valleys of S. Wales.

Wood for Power. Forests have also been drawn on to supply the mechanical power needed in modern life. We have just mentioned the demand for railway sleepers, but many railways have been run and some are still running on wood fuel, and examples can be quoted where the exhaustion of local supplies has

necessitated the creation of new plantations to maintain supplies (Kenya). In not a few cases, electricity generating plant is still today being run on wood fuel.

Hygienic Clearing. With the increase in knowledge of the methods of spread of disease among human populations and livestock, it has come to be recognized that in not a few cases the existence of forest cover is favourable or even necessary for the existence of carrier insects. This has led to a demand for further forest clearance, particularly around habitations and cultivated areas. The first instance of this kind was malaria; anti-malarial measures are various but always include the removal of any growth in which the mosquitoes may harbour or which facilitates their breeding. An even more outstanding example is provided by the tsetse flies of tropical Africa. Wholesale forest clearance has been recommended and indeed carried out in the campaign against the diseases of sleeping sickness in man and 'ngami' in cattle. Whether such clearance is essential and how far it is effective are matters still under debate and investigation, but meanwhile the destruction goes on, and forms a very serious threat to the forest in territories such as Tanganyika.

Tree Diseases. There is one more agency of tree and forest destruction that calls for mention, viz. the introduction from another country of a lethal disease. Several cases are now on record. Among them may be mentioned the chestnut blight which has practically eliminated a valuable tree from the mixed hardwood forests of eastern N. America; this disease is caused by a fungus introduced from Europe. Similar destruction has been wrought among the five-needled or white pines which are of much economic importance in

North America by a rust fungus introduced from Europe on cultivated currants, etc. The virus disease which is equally effectively destroying the valuable sandalwood tree in India must also fall into this category although we still lack precise knowledge about it. These matters will be further discussed in a later chapter.

Chapter V

FOREST INFLUENCES

IT has been shown in the foregoing chapters how the various processes involving the destruction of the forests have led to their disappearance from at least half of the original total area. We have next to consider the consequences of this wholesale clearance, apart from the obvious loss of supplies of forest produce.

Effect of Forest on Rainfall and Humidity. The influence of forests on climate generally, and particularly on rainfall, is a matter on which most diverse and contradictory statements have been made. In many parts of the world where water supply is the limiting factor to our use of the land or to industrial development, any such influence is obviously of great importance to us. It has very frequently been stated that the destruction of the forests in the Middle East and more recently around the Sahara has resulted in a reduction of the already low rainfall and the spread of desert and semi-desert conditions.

It would appear a simple matter to set up meteorological stations within a forest and under similar conditions of altitude and aspect in open country outside, and so to measure any differences there might be in the climatic factors observed. This has indeed often been done, but any conclusions drawn from the data obtained will always be suspect in the absence of proof that the differences are solely or even mainly due to the presence or absence of forest. So the more modern investigations have worked on the basis of

recording the data in a forested area for a number of years and then continuing the observations after the area—or preferably and more usually a part of it—has been cleared. The most comprehensive research so far undertaken examined incidentally the number of rain gauges that would be needed to give the degree of accuracy usually required in such experimental work, and found it to be an almost impossibly high figure. The conclusion to be drawn from all available sources is that a forest cover does slightly increase rainfall but only by about 1 per cent. An increase of this order might be expected from the lowering of average temperature, which will be discussed later.

It would not be expected that the forest could make any difference to cyclonic rainfall which is determined by atmospheric factors which are unaffected by a forest cover. It is however true that the effective level of the ground is increased by a forest to the height of the crowns, and a slight increase of 2 to 3 per cent. in precipitation may result. It has also been claimed on fairly satisfactory evidence that under certain conditions, the presence of forests may just tilt the balance causing the fall of a shower of rain which would otherwise not fall in that locality. Such 'instability' rainfall may be of considerable value to the farmer when it falls at a critical time for his crop, and examples have been reported from several parts of the world, though it cannot be claimed as a common occurrence. The humidity of the air tends to be slightly higher in the forest than in the open, not only the absolute amount of water vapour in the air, but also the more usual measure, the relative humidity.

Protection of Soil against Erosion by Water. When forest is cleared from the land, its place is sometimes

quickly taken by lower forms of vegetation such as scrub, grass or heath which continue to provide a measure of protection to the soil from the direct action of the rain, wind and sun. This is the case in most of Britain and the fact accounts in part for our slowness to recognize the inherent dangers of the removal of a protective tree cover from the soil. At the opposite extreme met with in tropical and sub-tropical regions, particularly where the climate shows alternating marked wet and dry seasons and the soil is in deep alluvial terraces, the results of forest denudation may be highly spectacular. What was formerly level and productive ground may in a relatively short period of years become a maze of deep ravines constantly eating further back into the remaining level ground. Such land is usually completely unproductive and a continual menace to the surrounding areas. Similarly, fertile hillsides may be reduced to bare rock in a relatively short time. To get a clear picture of how this has come about, it is necessary to consider what happens as the rain falling from the clouds reaches the top of an unbroken forest. When the drops first strike the leafy crowns of the trees, their speed of fall is checked, and they often break up into smaller drops before continuing their downward course. Some of the water wets the leaves and twigs and runs down the branches and trunk to the ground. Such drops as get through the various leafy layers to the ground will ordinarily fall on the low vegetation and leaf litter covering the soil. Even below the litter there is typically a porous absorbent layer of leaf mould or humic soil; rarely will a raindrop strike directly on the mineral soil.

As the rain continues to fall, the surface layers of

the soil become saturated and despite downward percolation can no longer absorb the total amount falling, and so water tends to collect on the surface and move down the slope. In its progress, this surface run-off will meet countless petty obstacles which delay its movement, giving more time for soaking in and ensuring that it moves with lessened volume and speed. Ultimately, it finds its way into the natural water courses and flows down them, still not having come into contact to any extent with mineral soil, and so remaining clear except for floating matter. There is another feature which characterizes forest soil in that by the natural processes of penetration, growth and ultimate death and decay of the tree roots ramifying everywhere in it, an open condition is maintained with a network of passages permitting downward and lateral movement. A grass cover may be excellent for filtering surface run-off and maintaining a good absorbent 'crumb structure' in the surface layers of the soil, but it is unable to affect the deeper layers in the way trees do. The water which thus percolates downwards ultimately reaches impermeable layers or actual rock and moving laterally emerges at the surface as a clear spring, or else it adds to the water table and well supplies. This downward flow is gradual and continues long after rain has ceased to fall, even for many weeks, and is of the greatest importance in maintaining the flow of springs and rivers: the streams run clear and constantly from a well-forested catchment as compared with brief torrents of muddy water from the denuded one.

When the forest is destroyed, the picture is entirely altered. The surface of the soil quickly loses the protective leaf litter and absorbent humic layer, and the

raindrops now strike directly on it with considerable velocity; downward percolation is much slower as the surface gets packed and the root channels fill up, and the surface run-off is proportionately increased in both volume and speed. The result is that the soil particles, beginning with the finest which are the most important for soil fertility, are picked up and carried away. In heavy showers, large quantities of mineral soil are washed away, and ultimately only sterile subsoil or hard rock remains where formerly a fertile soil existed. The size of the particles carried away increases very rapidly with the rate of movement of the water; doubling the latter results in an increase of particle size carried to thirty-two times its original volume. This destructive water erosion is accentuated by any form of soil working for cultivation or other purposes, by the trampling of livestock, or the removal by burning of such ground vegetation and organic detritus as remains.

Floods. Unfortunately, bad as it is, this soil erosion is not the end of the story. With greatly increased run-off during rain storms, the rivers will rise more rapidly and to a higher peak than formerly. This involves in turn more extensive floods and greater erosion of banks leading to loss of fertile alluvium, probably cultivated land, and sometimes to the changing of the course of the stream, with consequent extensive destruction. This tendency to alter course is greatly enhanced by an additional factor which comes into play directly the velocity of the stream slackens on reaching less sloping ground. The coarse gravel and boulders being pushed and rolled along its bed will stop and the soil particles carried in suspension will be dropped, first the fine gravel, next the coarse sand, and

so on down the scale to fine mud in the most level reaches. All this raises the bed of the river and sooner or later a breach of the banks becomes inevitable. Much of the tragic history of river floods in China must ultimately be traced to forest denudation in their catchments, and equally so in N. America. In passing, mention should however be made of the fact that not infrequently alluvial tracts may be largely dependent for their continued productivity on the fertilizing effect of the alluvial silt brought down by annual floods, but this fertility may well be gained at the expense of the higher land—in all too many cases, the maintenance of the fields below is at the price of the destruction of those in the hills.

Silting of Reservoirs. Under some circumstances this silt deposition may be fraught with yet further serious consequences. This is where the waters of the silt-bearing stream are impounded by engineering works to form reservoirs of water for domestic consumption, for irrigation or generation of electric power, or for both these purposes. The barring of the passage of the water stops or greatly reduces its rate of flow and therefore its silt carrying capacity. The burden it carries is deposited in the reservoir, and from the day of the closing of the barrage, the reservoir starts losing storage capacity. Engineers have introduced devices such as sluices at the bottom of the dam to pass on at least some of the silt, but most of the deposition will be taking place in the furthest parts of the reservoir several miles away, quite unaffected by such contrivances. It would appear that the only remedy is to prevent the silt from getting into the streams and reservoirs, and an effective vegetation cover is the best means to this end. In a study undertaken some years ago in N. America, it was found

that out of the sixty-six reservoirs examined, the average rate of loss of capacity through silting varied from 0·1 to 7·3 per cent. per year, implying an average effective life of under fifty years. In a number of instances, all storage value had been lost in thirty years, and in an extreme case 50 per cent. had been lost in seven years.

Water Consumption by Forests. This story of the effects of forest cover on water supply is still not complete. From the moment the raindrop strikes the leaf and spreads as a film of moisture, evaporation is taking place from the moistened surfaces. The amount of water lost by evaporation is usually compared with that lost by a free water surface. The annual loss from such a water surface may be the equivalent of 20–40 in. under temperate conditions, running up to 60 in. for the Great Lakes of C. Africa or even 14 ft. for the Dead Sea. The presence of a forest may reduce it to about half as compared with a fully open site. One would like to know whether more or less water goes back to the air from land with a forest cover or with ground vegetation only, or from bare soil. There is also another process linked with all plant life, namely the absorption of water from the soil by the roots and its 'transpiration' back as vapour to the air mainly through the leaves. Many studies have been made to obtain quantitative data as to the rate and total extent of this water consumption or transpiration. There are considerable difficulties inherent in its measurement under natural conditions and the available figures can only be accepted with reservations. As mentioned in Chapter I, the indications are that in temperate regions, the consumption by a tree cover of various kinds varies from the equivalent of about two inches of rainfall

(Scots pine) to about twelve inches (beech forest), these figures bracketing those obtained for grassland and agricultural crops. Data from tropical countries are even more inadequate, but one recent study led to much higher figures than those just quoted—in not a few cases more than the total recorded rainfall. The figure given for teak forest is about forty inches. It should be noted that these amounts of water are in no way wasted, but are consumed in the course of the constructive work of wood formation. On balance, it would appear that from the point of view of water economy, taking the combined effect of evaporation and transpiration into account, forest probably forms a more economical cover than any other type of vegetation, but uses up more water than is lost by bare ground. It must however be noted that certain detailed investigations have shown a greater stream flow in a forest area when the original tall tree growth had been replaced by a lower denser coppice and shrub growth, but we are not sure if this is always so.

Wind Effects. There is another atmospheric agency affecting the soil to an extent greatly influenced by the nature of the cover. This is wind, and its effects are particularly noticeable in hot climates with a long dry season. Moving air works on the soil in many respects like moving water. The size and weight of the particles which it can pick up and carry are closely related to the velocity of its movement. The amount carried off is proportional not simply directly to the velocity of the wind but to a high power of that velocity. Above a threshold value, which is nine miles per hour for dry fine sand, doubling the velocity may increase the size of the particle carried to eight times. As with water again, as soon as the velocity falls, the suspended

material is re-deposited. In this way a soil is sorted out into its constituent particles; the coarser are soon re-deposited as sand dunes and the medium sized as the *loess* or fine blown soils characteristic of the margins of deserts, present and past. The finest material may be carried right out of the region concerned, forming dust haze of a kind familiar for example to everyone south of the Sahara during the 'Harmattan' season. Most spectacular and potentially destructive are the sand dunes which move in succession down the wind and are capable of engulfing whole villages and irretrievably burying fertile fields. The fact that forest destruction, particularly on the desert fringes, leads to the increase and new formation of such dunes is incontrovertible, and there is now ample evidence that these dunes—as also those liable to form and move inland from sandy seashores—can usually be stabilized by restoring or creating a tree cover.

Fertile top soil can be stripped from arable land without necessarily forming sand dunes. This process has done enormous damage in large tracts, as in the middle west of N. America. Admittedly the original vegetation in this case was largely grassland, but the remedy has been found in the establishment of shelter belts of planted trees and shrubs breaking the force of the wind, thereby greatly reducing its erosive power, as well as giving the crops protection from direct wind damage. Such shelter belts have been raised on a very big scale, aggregating a length of some 35,000 miles in the U.S.A. Similar work has been done on a very big scale in the steppe region of S. Russia, and is now under contemplation in several other parts of the world. In the course of investigations to measure the effectiveness of such belts, it has been shown that the air velocity at

two feet above ground level is significantly reduced (by 20 per cent. or more of its original value) for a distance twenty-five times the height of the belt down the wind, and also three times the height into the wind.

Effect on Soil Fertility. Apart from these protective effects ensuring minimum damage from wind and run-off of water, the forest also plays a very important part in building up soil fertility. A productive soil owes its fertility to a very considerable extent to the favourable effect on its physical properties of the organic matter it contains—which we call humus. Apart from the quite small proportion derived from animal remains, this humic matter results from the decay of the vegetable detritus falling on it, or, in the case of roots, forming in it. It has been estimated that a fully stocked forest rains two tons of dead leaves, etc. on the soil every year in temperate regions, and much higher figures in the wet tropics. As soon as the leaves, twigs, dead flowers, etc. fall to the ground or the roots die, they are attacked by a variety of organisms, small animals, fungi and bacteria, and broken down, the ultimate residuum being dark coloured substances which have lost most of their original structure. These substances are gradually incorporated in the mineral soil both by the activity of some of the animals and by physical agencies. Not only do they improve the condition of the soil for plant growth but they gradually release for further use the essential nutrients they formerly derived from the soil, phosphorus, potassium, calcium and other minerals, also nitrogen in various forms. Our knowledge of the detail of the processes by which the leaf-fall is returned into circulation is still very inadequate, but the general lines are clear. One important point to note is that woody plants can

draw on the deeper soil layers that are often relatively rich in mineral nutrients, but out of reach for most herbaceous plants, and they are constantly drawing supplies from these deeper layers and ultimately returning them to the surface; this action is particularly important in the wet tropics. This process of soil enrichment by the forest is frequently indirectly acknowledged by the agriculturist when he removes the forest litter and green loppings from the trees for the purpose of fertilizing his fields. The recognized value of wood ash as a plant fertilizer may also be noted.

Effect on Temperature. The difficulties of determining the influence of a forest cover on temperature data are generally similar to those involved for rainfall, and how they have been met to some extent has already been described. Records have been collected for a number of years at a number of stations distributed over several selected forest areas and continued after a part has been cleared of trees. The outcome has been clearly to demonstrate a general moderating influence of a forest cover on temperature extremes, and a slight lowering of average temperature. In the summer, the maximum is reduced by about 5° F. and in the winter the minimum is raised about half that amount, though naturally there are considerable differences between different climates and types of forest. The cooling effect of a block of forest may often be marked by a 'bump' in an aircraft flying across the edge, even at 5,000 ft. or higher.

Value to Agriculture. The value of the forest to agriculture has emerged in several ways in this review. Probably the greatest single and permanent aid to agriculture is in the regulation and assurance of the

water supply, without which agriculture and indeed human settlement is impossible. To the protection provided by tree growth as shelter belts, etc. and the maintenance of fertility, has to be added the value of the great variety of products needed in connection with agricultural work and rural life generally. It may come to be recognized that the indirect help is more important in the long run than the direct, but as long as forests are maintained, for whatever purpose, they will continue to grow and yield their produce.

Biological Effects. Before closing this chapter, reference must be made to the value of forests as providing the necessary habitats for the preservation of many forms of animal and plant life for the interest and use of future generations. The gradual extinction of one after another of the larger forms of animal life is all too familiar. Apart from direct persecution, one of the main factors in their disappearance has been the destruction or excessive restriction of the habitats essential to them. It is not yet generally recognized how similar processes have been affecting many of the smaller forms of life, particularly the rarer which tend to be the more highly specialized and so more dependent on a special environment. Until recently this has tended to be viewed as a matter of sentiment rather than real importance, but it is now realized for example that we frequently need to go back to the residual natural vegetation in connection with selective breeding for the improvement of species important to us, or for biological studies of a fundamental nature.

Chapter VI

FOREST CONSERVATION AND PROTECTION

Conditions for Survival. Whilst the forest is exposed to the numerous, varied and powerful destructive processes that have been described in Chapter IV, there are one or two ways in which some areas at least have received a measurable degree of natural protection. The most potent of these is probably sheer inaccessibility, which has persisted in parts of the largest tracts of forest where population is still relatively sparse and requirements are easily met from the marginal parts. Many forests have been preserved through the steep and rocky nature of the topography they clothe, though when population pressure is high no such apparent inaccessibility will preserve the forest. Nearly half the total area of potentially productive forest in the world is still classified as inaccessible.

Mention has already been made of the important part played in the preservation of some forest areas from the onslaughts of man and his domestic animals by the fact that they may harbour disease-carrying organisms. There is today a serious risk that advances in medical and veterinary knowledge and techniques will expose these forests, which have hitherto been relatively immune, to the same uncontrolled destruction as has taken place everywhere else.

In a local and usually very restricted way, religious and superstitious beliefs have often protected patches of forest and groves of trees. Man throughout his history

has tended to associate his beliefs in the supernatural with certain groves or kinds of trees. A very good example of this is the cedar of the Himalayas, the name of which is *deodar* or 'God's tree'. The sacredness of the *bo*-tree to Buddhists and *peepul* to Hindus (both species of *Ficus*) has served effectively to preserve these trees in many places, whilst it is thought that the *Ginkgo* or Maidenhair tree of China is extinct as a wild tree, having been preserved only as a temple tree. The patches of *juju* bush in parts of Africa are a conspicuous feature. Not a few instances are known where foresters have taken steps to bring this protection to individual trees and groves likely to be damaged.

In the long run, perhaps the most effective protection forests have against destruction is the inherent resistance of some of the constituent species. In many forest communities one finds that certain trees have a truly remarkable power of recovery or regeneration after the harshest possible treatment. It is of course a common feature that the stumps of felled trees of many kinds will send up new shoots often capable of reaching the full normal size for the species in question. It has been remarked that the giant redwood of California frequently occurs in close clusters forming a rough circle, suggesting development from the shoots arising from a common parent stock. Besides these 'coppice' shoots from the stump, many trees have the power of sending up new stems from their roots; this tendency to produce root suckers is greatly stimulated by the felling of the tree and by severance or injury of the roots themselves. In this way the felling of a mature tree may result in the development of a whole group of young stems, as can often be seen in Britain with elm and white poplar, and similar occurrences are met with

in most types of forest throughout the world. Such trees are strongly favoured in the competition with others lacking these powers of recovery.

Fire Tolerance. The ability to withstand burning similarly varies greatly in different species. Whilst many are very sensitive and so are quickly and completely eliminated by recurrent fires, there are at the opposite extreme some trees which almost seem specially adapted to persist at least as a species through the severest fires. Thus there are several species of pine in which the cones are very slow to open and shed their seed, and this seed retains its viability for many years. When a fire sweeps through the forest, every tree may be killed, but the seeds survive and are released from the cones. The seedlings will meet with minimum competition from other plants which under normal conditions might be severe competitors, and may quickly and densely restock the area. The Lodgepole pine now being planted on some of our poorest sites provides a good example in its own home in N. America.

Resistance to Grazing. Very many trees are to an appreciable extent protected against grazing animals by thorn development in wide variety, though some browsing animals, notably camels and goats, seem singularly indifferent to the presence of thorns. More effective is the presence of distasteful or even poisonous substances in the leaves and shoots, as in the familiar cases of yew and oleander. The presence of such substances is frequently indicated by a corresponding odour which presumably warns off the intending maurauder before any damage is done, though once again some animals are not deterred but even the reverse.

General Hardiness. An interesting consequence of these varying powers of resistance to damage and destruction is found in the contrast and composition between the forests persisting under conditions of great pressure of this kind, and those that existed previously. A most striking example may be taken from a densely populated part of the Himalayas where on a long ridge ascending from tropical through sub-tropical to a temperate mountain climate, each altitudinal zone is associated with its characteristic forest type containing a considerable variety of species. The only remnant of the originally continuous forest was a restricted and now isolated area of tree growth in each of the three zones, each consisting almost exclusively of a single species. In the tropical zone, the species concerned (*Shorea robusta*) is characterized by very strong coppicing powers, tolerance of fire and hard unpalatable leaves. In the sub-tropical zone, there persisted a pure patch of a pine (*Pinus longifolia*) which has exceptional powers of fire resistance, regenerates easily, and is likewise unpalatable to stock. The temperate forest had been reduced to a single species of oak (*Quercus incana*) with similar powers of coppicing, and fair resistance to fire damage, though its foliage is in fact palatable; not far off could be found a pure patch of rhododendron (*Rhododendron arboreum*) which had outlived even the oak, thanks to its poisonous foliage and low fuel value.

Fire Risks. Reference has already repeatedly been made to the danger to the forest from fire. This question must now be examined somewhat more closely and the measures reviewed which foresters have developed to combat fire, though it is not possible to go into details. The risk of fire breaking out varies very greatly from

forest to forest. Many types are virtually fireproof owing to continuously damp conditions. Fire protection is no problem in the tropical rain forest or in damp montane types. In many other forests the danger period is relatively short, being limited to a season of low rainfall, particularly when this is combined with high temperature or wind. The greatest risk both for the starting of fires and for their spreading is met with in coniferous forests and forests in which grass predominates in the ground vegetation. There are also some dry shrubby types like the chaparral of W. America which are highly inflammable at certain seasons. In cool temperate regions there is often a special danger period in the spring just before the new growing season, through the accumulation of winter-killed ground vegetation such as the bracken and grass in Britain. In addition to the possible causes of fire already mentioned, some regions are subject to dry lightning storms which frequently start fires. One-fifth of all the fires in Canada are started by lightning and it is the chief single cause in several provinces, e.g. British Columbia; in New Mexico the figure is as high as 75 per cent. Railways are a particular source of danger to the forests through which they run owing to sparks flying from the locomotives, and special steps are necessary to minimize this risk. In the U.K. in 1950–51 out of 1,327 fires starting in State forests, 1,043 are ascribed to the railways, but as the danger is foreseen, prompt action is possible, and only fifteen acres were burnt as compared with 164 acres burnt by fires for which the general public was responsible. Reference must also be made to the special risks involved in connection with charcoal burning, slash disposal ('slash' is the crown and branchwood and

waste material generally accumulated during timber felling operations), and the routine burning of fire lines to be described later. Thirteen of the 1,327 fires started this way.

Fire Protection. The task of the forest staff in the matter of fire protection is twofold. Firstly, all possible measures must be taken to minimize the risks of fires being started from whatever cause; secondly, an organization must be maintained to extinguish at the earliest possible moment any fires that do start. It is usual in forests subject to fire to divide them up into blocks separated from one another in such a way that a fire is less likely to extend from one to another, and more particularly, that base lines are ready on which to stop fires. These fire lines or fire traces are usually cleared of tree growth for a varying width up to 100 ft. or even more, and it is usual to burn any grass or other inflammable growth under control every year before the season of high fire hazard sets in. In hilly country, these lines usually run along the tops of ridges and spurs, descending in places to streams or ravines which are sufficiently damp to stop fire. They may also be made round the edge of a forest property, but a contour line inside the forest is often dangerous to life and of little or no protective value against a fire spreading up a slope; nor will it prevent fire spreading downwards through rolling logs, cones, etc.

Fire Prevention. Measures to prevent fires starting are mainly concerned with giving the widest possible publicity to the danger and great damage which may result from carelessness. There are also some measures, such as the creation of special fire resistant belts along railways, roads and paths from which so many fires do in fact originate. Thus a strip of broad-leaved species,

particularly if suitable evergreens are available, can be used to protect coniferous forests and plantations. All inflammable material may be removed in a belt around danger spots such as frequented camp sites, etc., whilst a ploughed strip is particularly effective in preventing a creeping fire getting into the forest from outside, particularly from grassland or waste. In view of the risk of fires originating from logging operations, it is sometimes a rule that when the hazard is assessed as above a certain critical level, all work must stop despite the loss of output and the expensive waste of time involved; this practice is followed in British Columbia and elsewhere, and there are standardized ways of assessing the hazard.

Fire Spotting. Turning next to fire detection and fire fighting, the first requirements are for the earliest possible detection of a fire already in or threatening to enter the protected forest, linked with an organization for quick and effective counteraction. The general practice is to maintain lookouts at strategic points commanding an extensive view. These points are frequently hilltops and towers are often built to give the widest possible view. Whenever possible, they are so located that the smoke from a fire in any part of the protected forest could be seen from at least two of them. Each lookout is provided with a suitable map and a direction finder and is linked by telephone (or to an increasing extent, wireless) with the headquarters of the fire-fighting organization and the other lookouts. In this way it is possible to pinpoint a fire immediately it is detected from any lookout and to put the machinery in action for dealing with it.

Fire Fighting. The quickness with which action can be taken depends a great deal on the nature of the road

and trail network available to get men and all they require to the site. Simple implements such as fire beaters and caches of tools are commonly maintained at strategic points in the forest so that any labour which happens to be near the site can take immediate action. Extinguishing a fire soon after it has started may well be within the powers of a few men, whereas even minutes later, a large force may be necessary. The availability of mechanized transport has revolutionized forest fire-fighting methods and they have come more and more to resemble those adopted for dealing with fires in buildings. Formerly, it was rarely possible to use water at all, whereas now it is very common to do so, using fire pumps of various types drawing water wherever possible from streams and water holes or from reservoirs maintained for the purpose. The use of chemical extinguishers has been extensively investigated but it has not yet been found practicable to adopt them to any great extent. More modern developments may be mentioned, such as the use of aircraft patrols in spotting fires, and parachutes for dropping men ('smoke jumpers') and supplies near fires otherwise difficult of access; helicopters have been found useful for directing operations. Canada and the U.S.A. lead in these matters.

Counterfiring. A procedure very commonly adopted is deliberately to start a fire from a safe base line, often one prepared in advance against such emergency, and let it run to meet the advancing uncontrolled fire: when fire and counterfire meet, they mutually extinguish each other. This method is helped by the fact that a big fire always causes an inward draught, drawing the flames of the counterfire towards it and reducing risks of its spreading in the wrong direction.

Fire Losses. Development of all these methods has greatly increased the efficiency of fire protection and fire fighting, and brought about a great reduction in the extent of the annual losses. Even so, fire protection is still the most important forestry matter in the coniferous forests of N. America involving an annual expenditure of 1⅓ million dollars in Canada and a considerably higher figure in the U.S.A. which works out at about three cents per acre of national forest protected. In some parts, all forest owners pay an annual cess on their acreage for maintenance of a common fire-detection and fire-fighting organization. It may be added that it is possible in many countries to insure forests against fire risks though the usual difficulty arises that it is not easy to relate the premium to the risks incurred under the very varying conditions. Most of the insurance is consequently carried by mutual societies of owners; the woods are classified by risks, and premiums vary from 2/- to 20/- per £100.

We may leave this subject with a mention of a few representative statistics. The average area burnt over in State forests in Britain during the five years 1947 to 1951 has been 695 acres by a total of 1,037 fires, the largest having been 170 acres. The financial loss from fires was assessed at £45,000 in 1948, a bad year. In 1950, British Columbia reported an area of 848,246 acres burnt over in 1,515 fires, three of them over 200,000 acres each.

Early Burning. There remain one or two incidental points worth notice before turning to our next subject. It is often the position that the damage done by an accidental fire after a period of successful protection may be much greater than would have occurred from a fire even at the worst time of the year when there was

only one year's accumulation of inflammable material present. Where the risks of accidental fire are high, this experience has led to the adoption of a practice of intentional burning early in the season before the soil and surface cover have fully dried out. At this time a fire can often be run with very little damage to established tree growth, and under the right conditions even small regeneration may escape serious damage. It has been found in many fire-swept open savannah forests that the tree growth will fill up in a most striking way during the course of a few years of this treatment, and this method of early or controlled burning has spread considerably of recent years in India and Africa. It has possibly spread more widely than is in the long run desirable, since it unquestionably often has an undesirable effect on the soil and may encourage erosion. It amounts, after all, to a confession of failure.

On the other hand, it has also to be noted that there are not a few instances in which the kinds of tree dominating with a regime of burning may be economically more valuable than those which would take possession with full protection. This possibility as applied to teak, a tree which far exceeds all available alternatives in economic value, has in the past been the subject of acute controversy. It is also possible that with fire protection, excessive amounts of undecomposed or 'raw' humus may accumulate on the surface of the soil reacting unfavourably on its productivity and retarding or inhibiting natural regeneration. It may be necessary to remove this excess by burning as a direct measure during regeneration operations. Examples are common among conifers, but also occur with some hardwoods.

Regulation of Fellings. Prompted by shortages of timber and fuel, the realization spread some centuries ago in the countries of western Europe that steps had become essential in the general interest for the protection of the forest, and measures were devised towards this end. The first steps taken were usually the reservation of an adequate number of trees per acre to ensure a seed supply for natural regeneration, and the maintenance of an appropriate proportion of trees of timber size. Prescriptions were also gradually introduced limiting the fellings to specific areas or 'coupes' in which further fellings were not permitted until the lapse of a specified period. Usually there was also some differentiation between the different species present with a view to the special protection of the most important.

Regulation of Grazing. It also came to be realized how detrimental unrestricted forest grazing could be, even to the extent of practically preventing the establishment of regeneration. Either such grazing had to be stopped entirely or at least it had to be restricted to reasonable numbers of stock, and often to specified times in the year when the damage would be least. In not a few cases, the history has been that where grazing rights extended over a forest, agreement has been reached whereby they were relinquished in one part in exchange for the complete handing over to the right-holders of another part, usually that nearest their village. Forest grazing in Britain by right-holders occurs in the New Forest where also 'pannage' of swine in the forest is open from 25 September to 22 November annually. Out of the total of 23,783 acres of Crown woodland, 16,000 may in fact be closed to cattle grazing at any one time, though an additional 5,000

acres has recently been agreed under certain conditions. In Britain, goats and sheep are legally not 'beasts of common' and cannot be grazed under commoners' rights. This question of the regulation of forest grazing is very acute throughout India where the number of cattle of all kinds reaches nearly the same enormous total as the human population, and many forests are burdened with an incidence beyond their maximum possible carrying capacity. Investigations are in train to determine how to deal with the matter. It should not be overlooked that sometimes conditions may exist under which the best use of the land may be a regulated combination of grazing and forestry: these problems of 'range management' are important in several of the States of U.S.A., and in many alpine regions.

Protection against Wild Animals. Reverting to the view of the natural forest as part of a complex of plant and animal communities which have evolved together developing a considerable measure of interdependence, it is to be expected that some of the influences of the animal life on the trees are not of a nature that is favourable to human interests. As long as forestry is extensive rather than intensive, and there have not been disturbances of balance resulting in an abnormal increase in numbers of injurious animals, the damage done by wild life in the forest is unimportant, indeed its presence may be welcome. But as soon as the forester begins to aim at maximum production per acre with well-grown trees, he finds that the damage done by wild life either directly by feeding, or indirectly as for example when deer rub the velvet off their horns, is quite often significant and cannot be ignored. Trees in the seedling and sapling stage are

particularly exposed to damage or destruction, and natural regeneration may be almost completely inhibited by wild animals even in quite moderate numbers. Regeneration operations often have to be concentrated in selected areas, and the browsing animals are more than likely also to concentrate on those areas.

Fencing. This situation often forces foresters to fence regeneration areas and plantations, an expensive operation—currently about £12 per acre in Britain. The type of fence required will vary considerably with the size and habits of the animals to be excluded. It may have to keep out deer, large or small, wild pig, porcupine or rabbits. For the larger animals, some type of wove-wire fence about 4 ft. high is needed with an appropriate number of strands of barbed wire above it up to 7 ft. from the ground. Pig and rodents will attempt to dig under the fence so it is necessary to bury the bottom part in the soil, and it is usually necessary to lap the buried part outwards as is done with rabbit netting. The electrified fence has sometimes been found effective where other types have failed especially for the larger animals (even elephant). Fences unfortunately will not exclude all injurious animals; thus quite different measures are necessary to deal with the grey squirrel which is doing such extensive damage to our hardwood areas in Britain, and monkeys are equally difficult to exclude. Even birds can be very destructive in plantations, for example, black game which feeds on buds of Scots pine, and to regeneration by taking the seed of both hardwoods (wood pigeon) and conifers (crossbill): the only remedy is to keep their numbers down to reasonable figures.

Insect Damage. Turning next to the protection of the forests from undue damage by injurious insects, we

find first that there seems to have been a very great increase in insect pests since forestry work has been more organized and carried out on a large scale. Considerable alterations have been brought about in the composition of the forests themselves by the introduction of management, particularly an increase in the proportion of the few more valuable species as compared with the more or less varied natural forest of earlier days. These epidemics have struck both broadleaved trees and conifers. Thus wide stretches of forest have often been completely defoliated by millions of caterpillars of one or more kinds of moths or sawflies. The consequences are more disastrous with conifers than with the broadleaved trees owing to the much smaller power of the former for regenerating lost foliage, and the result is frequently a wholesale death of the defoliated trees. On Scots pine, there are several serious defoliators often simultaneously, viz. the pine looper, the pine beauty, the pine hawkmoth and the nun moth; the best known cases with broad-leaved trees is due to the attacks of the caterpillars of the gipsy moth. In England, it is a common sight to see oak woods completely stripped of their new foliage in the first few weeks of summer by the *Tortrix* leaf roller, and in the tropics a similar condition is often found with teak, though here the large leaves are skeletonized rather than totally consumed. In N. America, enormous damage has been done by several species of bark beetle (*Dendroctonus*), the larvae of which feed on the inner bark of the living pine and other trees. In Canada, the ravages of the spruce bud-worm have similarly killed an enormous number of trees, and the total annual wastage from insects and disease is estimated at the astronomical figure of 500

million cubic feet, twice the losses from fire or a sixth of the total fellings.

Besides epidemic devastation, a great deal of scattered damage of the same type is always taking place, and the presence of the pest concerned generally carries with it the threat of development of an epidemic outbreak. A number of insects attack the leading shoots of growing trees causing forking or deformation which seriously depreciates the value of the timber subsequently formed. In Britain we have a minute moth larva which kills the leading buds of ash, and a small group of moth larvae which hollow out and kill the buds and developing shoots of pine trees; many important tropical trees of the family *Meliaceae* are similarly attacked. Other insects feed underground on the roots of plants including trees, the most destructive in forest nurseries being the grubs of the cockchafer beetles.

Insect Damage to Timber. There are also many kinds of insects which do not usually kill the tree attacked but may cause serious deterioration in the value of the timber produced. There are many wood-boring beetles and not a few wood-wasps and moths which cause damage of this kind. The goat moth, and the beehole borer of teak, various Longicorn beetles and the giant wood-wasp (*Sirex gigas*) may be quoted as instances. Passing mention must be made of the many other kinds of injurious insects which attack the tree immediately it is felled, reducing the value of the timber. This is particularly true of the many pinhole borers (small beetles mostly belonging to the families *Platypodidae* and *Scolytidae*). Fungi which stain the wood causing further depreciation are often introduced at the same time. There are yet other insects which

attack dry wood, e.g. the furniture beetle (*Hylotrupes*), the powder post beetle (*Lyctus*), and the well-known Death-watch beetle (*Xestobium*). But the greatest damage of all is done by termites (white ants) in hot countries, particularly to timber in buildings. Only a *few of the heavy hardwoods are sufficiently resistant* to withstand their attacks without preservative treatment with creosote or other chemicals. Mention must also be made here of the shipworms (*Teredo*, etc.) which bore in timber used in marine piling and ship-building and are a serious menace—these are of course not insects but molluscs.

Control of Insects. It cannot really be said that the position is very satisfactory as regards the prevention of these attacks or the control of insect epidemics. There are two possible lines of action, the direct and the indirect. Direct measures include spraying or powdering from the ground or the air with poisonous chemicals of which the efficiency has been vastly improved of recent years by the discovery of such types as D.D.T. Some of the new substances can be applied to the roots of the tree which absorb them without harm and pass them on unchanged to the parts attacked by the insects: the drawback at present of these 'systemic' insecticides is their very poisonous nature to man also. Diseases such as the polyhedral diseases (viruses) affecting caterpillars have also been used for control purposes.

Another line of attack is the use of attractants of various kinds for collecting and destroying insects in the free-moving stages. Thus some of the insects attacking coniferous trees can be collected for destruction by placing out suitable billets of fresh felled timber which attract them. Use has also been made of the fact that

many moths and other flying insects are strongly attracted to a bright light, but the weakness of this measure lies in the fact that most of the insects attracted are only the males, or if females, have already deposited eggs for another generation.

Biological Control. Turning to the indirect methods, these are mostly covered by what is described as biological control. This starts from the idea that in nature the numbers of any one form of life remain roughly constant under natural conditions, being determined by the balance between factors favouring and hindering its always great powers of multiplication. Among the unfavourable factors are parasites and predators large and small, and adverse climatic conditions of heat, cold, moisture, light, etc. On the insect's side will be favourable climatic conditions and anything limiting the numbers of its enemies. Biological control consists in attempting to maintain the natural equilibrium and if possible to give it a turn setting it at numbers of the pest species even below the normal figure. This may be done by such restricted manipulation of the physical site factors as may be possible, for instance by letting in more light and wind, or measures such as deliberately bringing in more predators and parasites, or encouraging conditions conducive to their natural increase. The problem is a complex one which cannot be further discussed here, and it has always to be remembered that whether steps are taken or not to cope with an epidemic at its height, it is certain that the numbers will subsequently fall. The realization of these facts has led to the focussing of attention on the need for bringing about conditions in the forest such that the chances of an epidemic developing are as low as possible. In a general way, this involves some

measure of return from excessively artificial conditions such as usually exist in a pure crop of a single species, and in the encouragement of a rich mixed flora and fauna that will be continuously present to play its part in checking at an early stage any undue increase of an injurious species. It must be borne in mind, however, that with the widespread use of exotic species and of indigenous species beyond their natural range, and the increasingly common occurrence of the accidental introduction of an insect from one country to another, there remain chances of the development of epidemics. In such cases control may be possible by the artificial introduction of the parasites, etc. which control the pest in its own home.

Fungus Damage. Next for consideration come the injurious fungi and related organisms. One of the most conspicuous examples of damage to living trees by fungi in Britain is provided by the elm disease which, first noticed near London in 1927 and believed to have been introduced from Holland, has killed very large numbers of trees. It is spread by a bark beetle which breeds in the bark of unhealthy trees and carries the spores adhering to its body to new trees. The killing out of most of the chestnuts in N. America is similarly due to a fungus disease (*Endothia parasitica*) to which they are not resistant: this fungus appears to have been accidentally introduced into the U.S.A. from Asia about 1904, and later in 1938 into Italy where, too, it has spread widely. The honey fungus (*Armillaria*) often kills many young trees in coniferous plantations, particularly where they have been raised on the site of former hardwood forests. This fungus develops in the decaying stumps and can then spread through the soil to attack the roots of young planted trees. Another

form of damage that may be serious is due to the mould fungi which are liable to attack young seedlings in the nursery bed or on the forest floor before they have hardened up. These 'damping-off' fungi may wipe out large numbers of seedlings, but fortunately they can be dealt with, e.g., by the application of a solution of potassium permanganate.

Some species of rust fungi which attack coniferous seedlings may also call for special measures, and may render advisable the concentration of nurseries in places where the appropriate measures, e.g. periodic spraying with Bordeaux mixture, can be effectively carried out. This is done with Scots pine on the Continent to protect it against a needlecast disease. Another rust fungus, a blister rust (*Cronartium ribicola*) has caused widespread mortality among the five-needled pines both in N. America, where it is still spreading and constitutes a dangerous threat to the important Western white pine and Sugar pine, and in Europe. This fungus must pass part of its annual life cycle on shrubs of the genus *Ribes* (currants and gooseberries) so that it cannot spread to the pine if no *Ribes* are present. This obviously suggests that *Ribes* should if possible be eliminated from the threatened forests and their vicinity, but this is not usually practicable. The prevalence of this rust makes it impossible to raise plantations of the Weymouth pine (a native of N. America) in Britain.

Bacterial Diseases. The diseases affecting poplars, both leaf rusts and the bacterial disease that causes the cankers often to be seen on them, are of interest and importance. They have been intensively studied and are the subject of special legislation in several of the western European countries. It has been found that

the different species, hybrids and strains used vary greatly in their susceptibility to injurious attack, and the regulations in question aim at discouraging the use of susceptible types and restricting sales to stock certified as resistant.

Virus Diseases. Trees are also susceptible to virus attacks, the best known causing the spike disease which is very lethal to sandalwood in India. This case is of particular interest in several respects. The sandalwood tree is semi-parasitic, establishing root connexions with other trees from which to a considerable extent it draws its supplies of nutrients. It parasitizes in this way a considerable range of plants, frequently making a start on a short lived temporary host before it finds the long term connexions on which it is dependent in later life. It occurs scattered more or less sparsely over a wide tract of country and appears still to be spreading; in fact there are good grounds for thinking that in India it may only have the status of an introduced species brought in because of its use in connexion with religious ceremonies. One considerable extension of recent years appears to have followed the spread of another accidental introduction, the scrambling *Lantana* shrub from Mexico. Spike disease, which takes its name from the appearance of the abnormal shoots which it induces, is believed to have been introduced into India towards the end of the nineteenth century, and its subsequent erratic spread has been very difficult to understand. Thus, it appears to have jumped more than one hundred miles under conditions which make it difficult to conceive what the transmitting agency could have been. A great deal of work has been done without entirely clearing up the problem, though the study of other virus diseases, particularly those

attacking horticultural crops, has been very fruitful of suggestions. There is no doubt that plant-sucking insects are the carriers or 'vectors'. At one time the evidence seemed to suggest that infection was most likely to take place about 2 o'clock in the night! Complications arose from the fact that a tree may have the disease for some time without showing it, but if such a tree is stimulated to rapid growth, as by coppicing or heavy pruning, it will show the reduced leaf, etc. of the spiked condition. Attempts to transmit the disease artificially were for long unsuccessful but it can now be done by grafting leaf tissue. It has been found that the resistance to infection differs according to the host plant parasitized, and sandal growing on *Lantana* is highly susceptible. No effective method is yet known for combating this disease which invariably kills the tree attacked. Meanwhile fellings have to be limited to dead and affected trees since these often make up the whole permissible cut.

Timber Fungi. Just as with insects, so also may fungi bring about serious deterioration of timber. The heart-wood of trees is in fact dead material, and fungus attack once initiated may spread right through it as heart-rot of one kind or another, so that the log becomes valueless as timber. Some kinds of trees are particularly susceptible to attacks of this kind, so that a large proportion of the crop may become worthless. The method of entry of the fungus varies considerably and may be through the stem, branches, or roots, any injury to which may increase the risks. Thus the prevalent practice of lopping the branches of blue pine in the Himalayas for fuel has brought about a very high incidence of attack by one such fungus, and the cutting of Scots pine roots in opening boundary ditches or

drains may have a similar result. Frost injuries and fire scars may also facilitate the entry of such decay. Some of the fungi attacking living trees may also attack timber after it has been felled and put to use, whilst others, such as the all too familiar dry rot, are rarely met with except in timber structures. Timber may be considerably reduced in value by certain staining fungi which are often spread by the pin-hole borer beetles already mentioned. The relation between insect and fungus is of considerable interest, as there is a measure of mutual dependence, the insect larvae feeding on the fungus growth.

Damage by Natural Agencies: Wind. The next category of injuries against which forests must be protected are the injuries caused by natural agencies such as wind, lightning, snow, cold, drought and heat. The stunting and often disruptive effects of wind on tree growth are very well known in Britain. They are reflected in the common practice of retaining a protective belt around a wood under felling, particularly on the exposed windward side. Foresters have learnt by expensive experience how dangerous it is to expose to strong winds stands of trees which have hitherto had the protection of adjoining tree growth, and this risk has constantly to be taken into account when planning fellings, or indeed much earlier, when planning the general layout and working of a forest. The general principle involved will thus always be to try to start felling on the leeward side and fell into the wind. It may also be noted that this felling direction ensures that in the case of wind-borne seed, the seed will tend to reach the ground where trees have been removed and regeneration is needed. The extent of the mutual protection of trees growing as a close crop is

well illustrated by what can commonly be seen to happen to the tops of Douglas fir trees when, through their exceptionally rapid growth, they push up above the general level of the tree canopy. Heavy thinning always involves a risk of wind damage.

Lightning. It is not necessary to say much about damage by lightning since no possible control measures are available. The varying degree of risk associated with different kinds of trees finds expression universally in familiar country sayings, though not infrequently the cause for a high or low incidence may be related to the site favoured by the species in question rather than to its individual characters. The effects of lightning seem to vary most erratically; sometimes the damage is restricted to the tearing off of the limbs of a tree, sometimes the charge is conducted to the ground through the living tissues with the rupture of a strip of bark from the top to the ground without necessarily seriously affecting the vitality of the tree. The blaze caused often follows the direction of the grain of the tree and may even encircle the trunk two or three times. Not infrequently however, the damage is more serious and the tree may be girdled and killed. It has frequently been noticed that a lightning-struck tree may survive several years but then ultimately die, and sometimes the surrounding trees also die at the same time or subsequently. This phenomenon may or may not be linked with the attack of the struck tree by insects or fungi and their subsequent spread. We have already noted that lightning may be a frequent cause of fire. This is particularly likely to happen when the struck tree has dead or rotten wood which may smoulder for days until fanned into sparks and flame by the wind.

Snow Damage. The risks of damage by snow are often high. The actual damage is usually the uprooting of the trees that may occur when large weights of snow accumulate on the crown at a time when the ground is not frozen. The fall of a few trees in a closed crop may lead to the throwing of a large continuous area, each tree in turn throwing the extra fatal weight on its neighbour. Even a slight wind may produce this result with snow-laden trees. If the trees have a firmer hold on frozen soil, it is the stem that gets broken, and this form of damage is also liable to occur on a big scale. Evergreens naturally collect greater weights of snow than deciduous trees and so suffer more, though abnormally late falls may greatly damage deciduous trees already in leaf. The worst instances of both types of damage have been recorded for spruce where it has been planted extensively at altitudes lower than those at which it occurs naturally. Widespread if less permanent damage may be caused by the bending or the breaking of the tops of young trees as not infrequently happens in plantations of larch, etc. in this country. Many trees of high altitudes are remarkably well adapted to withstand damage by snow, but some species such as larch growing on sloping ground are liable to acquire a permanent sabre-like basal curvature from the pressure of snow. The contrast between the curved larch and the erect Cembran pine growing together in the Swiss Alps is sometimes quite striking. Somewhat similar to the damage by snow is the damage done under special conditions when atmospheric moisture congeals as ice in large quantities on the branches and twigs of trees. There was a remarkable instance of this in the 'glazed frost' of January 1940 in parts of southern England, beech being the chief sufferer.

Frost. The occurrence and severity of frost is one of the most influential site factors determining the distribution of plants, since many species are quite unable to withstand its effects. Relatively few tropical species can survive it, though some such as teak may be damaged but not eliminated, owing to their strong coppicing powers. In regions in which frosts do occur but not very frequently or severely, many trees are able to establish and maintain themselves with the help of the protection afforded to them in their younger stages by the already existing tree growth on the area—for temperature is usually lowest near the ground and in the open where loss of heat by radiation is at its maximum. Clear or heavy fellings have indeed often resulted in the introduction of frost damage where it hardly occurred before. There are three types of damage to be noted. Firstly, the low temperature may kill the living tissues of the parts that at the time are still active or not yet sufficiently matured. The leading shoots of ash and spruce and other trees may thus repeatedly be killed back, particularly in low-lying sites where cold air is liable to accumulate. The loss of its leader may be a serious handicap to the survival of a plant against competition, quite apart from the damage done from the point of view of the loss of growth and lowering of timber quality; in frosty sites, where the choice is available, as is the case with Norway spruce, it is important to avoid using stock which will shoot early. It is an interesting fact that in not a few plants, for example some kinds of silver fir, growth in the leader begins definitely later than in the side shoots, so that the former may escape damage from a late spring frost severe enough to kill back the side shoots, whilst on the other hand, no time is lost for growth in normal years.

Frost Split. Exposure to very low temperatures not uncommonly results in the splitting of the trunks of trees to a varying depth in a vertical radial plane. Under the right conditions, the rupture may be heard to take place like a pistol shot at the coldest time of the day or night. The fact of its occurrence may later become apparent by sap flow from the rupture, but this is not always the case. With return to normal temperatures the crack formed closes up and cambial activity seals it. It remains however a line of weakness and may be re-opened repeatedly. Ultimately a raised scar or 'frost rib' is formed indicating the existence of the hidden defect; such frost ribs are all too common in oak growing in frosty hollows.

Frost Lift. The third form of damage from frost is very different, being the throwing out of the ground of young seedlings growing on loose soil. This phenomenon of 'frost lift' occurs through the growth of ice crystals in the soil pushing up its already frozen surface layer together with the seedlings fixed in it. Seedlings may be pulled several inches out of the ground in this way and injured beyond recovery. The chief remedy is to avoid siting nurseries in places where it is known that the trouble may occur.

Drought. Periods of exceptional drought may do considerable damage to forests and plantations, both directly by killing trees outright or by killing back the tops and branches, and indirectly by favouring the entry and development of decay in the timber. Dry weather soon after planting commonly leads to heavy mortality, particularly on light soils and hot slopes. Severe drought, particularly if repeated or continued over successive years, may result in the drying out of the upper soil layers in which most of the roots are

found and a marked drop in the water table. This may reduce the water that can be absorbed by the roots below the quantity necessary to keep the crown alive, and it will die back to a varying extent. The roots are also similarly affected and they, too, die back and expose the whole tree to the attacks of rot-causing fungi present in the soil, so that even if the crown subsequently recovers, risk of wind-throw is greatly increased and heart-rot is likely to have set in. A drought period of this kind in 1907 and 1908 caused the death of at least half a million sal trees in N. India, and very serious mortality among the hardwoods planted in the shelterbelts of the Ukraine has been recorded after drought periods.

Damage by Man. There remains an aspect of forest protection which might perhaps have been taken earlier, namely the protection of the forest against the various injurious activities of man. Most of these have already been mentioned in different connexions, and it has been noted that the stage has often been reached where restrictions and regulations aiming at moderating these practices have been imposed more or less by common consent. Most countries have ultimately found it advisable to draw up and enact special legislation, the main purpose of which is to protect the forest areas to which it applies from further damage. Where a considerable area of forest land, actual or potential, still exists, the first step has usually been to demarcate those portions of it which are to be maintained as forest and to which the special protective legislation will apply. This procedure, together with the legal enquiry to establish and to define any adverse rights which may exist over the land itself or the tree growth, is usually termed a *forest settlement* or *reservation*. In

Britain, where publicly owned land is rarely available for forestry, the procedure is naturally different and involves the negotiation with existing owners for acquisition by purchase, though the powers exist to acquire land compulsorily in certain circumstances, due compensation being payable. A passing reference is necessary to the way in which rights over forest may come into existence. The commonest method of origin is what is known as 'prescription' which amounts to undisturbed practice for a long period of years. Thus, if a local farmer has been accustomed to collect the fuel he requires and cut poles for his agricultural needs from the woodland adjoining his farm but belonging to someone else, and no objection has been raised to his doing so 'from time immemorial'—in practice, over a period of thirty years—then he has acquired a 'prescriptive' right to continue to do so. Usually such prescriptive rights can no longer accrue in a forest that has been legally constituted a State reserve. Rights to produce cannot in the aggregate legally exceed the amount which the forest can continue to yield without detriment to its future production. Forest grazing and removal of fodder and litter have to be regulated in the same way. Apart from these rights to produce, which if not properly regulated may lead to the deterioration and possible final destruction of the forest, there are many other activities injurious to the forest which must be limited as far as possible. Forest Acts accordingly make provision in these matters, e.g. by limiting any dangerous use of fire. Machinery is necessary for preventing or regulating all such practices, and taking action against offenders. Usually the forest staff in State forests has limited powers of arrest, and of seizure of the produce concerned and any vehicle or

tools used in connexion with the forest offence. They may also have powers of inquiry, including the summoning of witnesses, recording evidence and fixing and accepting monetary compensation as an alternative to prosecution in a court of law.

Chapter VII

FOREST DEVELOPMENT AND INDUSTRY

Survey of Resources. When the necessary measures have been taken to ensure adequate protection of a forest as described in the foregoing chapter, the question of its development as a source of material comes into consideration, though it is unfortunately true that felling operations have often not been postponed till this stage has been reached. Among the steps called for is a survey of the resources that the forest contains and of the potentialities for future growth. The first requirement is some form of topographical mapping, though in the less developed regions this is often done as part of the forest survey itself. The need of good maps for forest work is so great that detailed forest mapping has sometimes been pushed ahead of the general survey work, as was done in India. The operation of estimating the contents of a forest before timber extraction work is commenced is generally known as 'cruising'. It is most usually done by running lines distributed uniformly over the area of the forest and examining and measuring the trees growing on strips along these lines. The proportion borne by the area of the strip examined to the total area varies with the intensity of work and the accuracy demanded. Typically, it ranges from 1 per cent. to 5 per cent. In cruising a forest area in this way, a great deal of additional information may be collected for the pre-

paration of a working topographical map and for determining road alignments, etc.

Stock Maps. In the more intensively worked forests, still more information is recorded leading to the preparation of a *stock map* which shows the varying types of forest met with, the proportions of the different species present, the size classes of the trees, the nature and extent of regeneration if any, and so on. This stock map forms the basis for the management plan to be discussed later. Of recent years, it has been considered necessary in several countries, including Britain, to undertake a national census of the forest and timber reserves, irrespective of their ownership. This is done on highly standardized lines, and may be repeated at intervals of say ten years; thus Sweden is at present carrying out its third decennial census, maintaining a special permanent staff for the work. A 5 per cent. sample is usually considered adequate for this purpose. A full census of this kind was completed in Britain in 1951 after earlier less accurate ones done in 1924, 1938 and 1942.

Communications. An adequate system of communications is essential to proper forest development and management, though what is required varies considerably with local conditions. The very important part played by waterways in the past has already been mentioned, and they are still of great importance, particularly in coniferous forests, as nearly all coniferous timbers can be floated. Although even the majority of commercial timbers in the hotter countries are too heavy for floating by themselves, extraction by water is still often very common: thus the greater part of the world's supply of teak timber is extracted from the forests by water. It so happens that teak wood sinks

when green, but after it has been well dried it will float for a sufficient time to be rafted out before re-absorbing so much water that it sinks. The drying out is ordinarily effected by girdling the standing trees several years before they are felled. Alternatively, the teak or other heavy timber may be bound up in rafts with lighter timbers, or with bamboos which are very buoyant. It is also possible to suspend timber too heavy to float alone, from boats of various types. Here the buoyancy of the water takes the greater part of the weight and the boat has only to support the remainder. The reason for the continued prevalence of water transport of timber is that it is very much cheaper than any other form, though it is admittedly slow, and involves appreciable losses from sinkage, breakage, etc. Water transport is particularly highly developed in the Scandinavian countries with their exceptionally good network of rivers and lakes. It is also very convenient to be able to deal with logs floating in water when sorting them into species and sizes before feeding them into a sawmill.

Slides and Ropeways. Even where the waterways are suitable for the purpose, special arrangements are often necessary to get the timber from stump site to the floatable stream. A great many different methods are in use to bring timber down to the waterways and roadways. It is common practice with logs and still more with sawn timber of more or less standard dimensions, e.g. railway sleepers, to construct out of the logs or pieces slides down which the timber can be quickly conveyed. Such slides may be used dry, but where it is available, water is generally used in them to facilitate movement. Special attention is needed to gradients and curves if the work is to run smoothly and without

danger to the workers. Aerial ropeways have also frequently been installed and are particularly useful in hill forests for bringing down timber over steep rocky ground. The precise siting of all such devices is also very important from the point of view of economic working.

Animal Haulage. Animal haulage is still much used in the forest particularly for collecting timber at points from which other forms of transport are in use. In the northern hemisphere, horses are often still the best and cheapest method for hauling out light material, such as thinnings, fuel, etc. through a standing crop, particularly when snow is covering the ground; various types of sleigh may be used in this work. Teams of oxen and buffaloes are used locally in a similar way. Elephants are still invaluable for handling timber in some eastern tropical countries, particularly for getting teak timber down to and along the smaller floating streams.

Roadways, etc. As a supplement or alternative to the waterways, a network of roads and paths is usually necessary, if only to facilitate access and supervision of work. In many forests, timber is still sawn up at the felling site and carried out by man-power, but this is becoming less common. Animal transport is usually cheaper than man-power for the purpose, though there are rather strict limitations as to the size and dimensions of the timber that can be so carried by horse, oxen, or camels, all of which are used for the purpose. In hilly country, suitably graded pathways facilitate and cheapen the work, and on level ground, carts usually replace pack transport. In some of the bigger forest areas of the world, the logging railway took the place of transport by animals at an early stage.

Railways. Alignments have to be much more carefully run for railways than for roads, permissible gradients and curves are much reduced, and the problems involved become those of engineering. There are many respects in which the details of construction of temporary logging lines differ from those necessary for permanent installations and for passenger traffic. Logging railways and the smaller tramways are however being in turn rapidly displaced by the great development of road and track-laying transport and tractor vehicles.

Motor Transport. There are so many advantages associated with mechanized road transport as compared with any of the other alternatives, that it is rapidly becoming the predominating method. More attention is now being given to the building up of the roadways required for the first working of a hitherto undeveloped forest area into the permanent network required under the long term view. Where annual or short term timber leases are granted, it is often laid down that the roads to be constructed shall fit into such a long term plan. Modern equipment is capable of tackling the largest logs even in the remaining virgin heavy timber tracts, and carriers and roadways capable of taking loads up to seventy-five tons are met with. In some cases, regulations for the use of the public highways necessitate the breakdown of timber loads when they come off the specially constructed forest extraction ways on to the public highways.

Skidding and Tractors. Mechanical devices are also extensively used in collecting timber at points on the railways or roadways, mostly covered by the general term 'skidding'. This part of the task has been very highly developed, especially in N. America. The use of track tractors has rapidly spread for both large

timber and small. The great advantage of these tractors is that they do not require a prepared trackway, but can go directly to each log, even on quite steep ground. In this way, particularly when equipped with winches, they have already to a large extent replaced both the horse and skidding engines. It is probable that tractors often do more damage to the roots and bases of the standing trees than the other methods formerly prevalent, but this possibility does not usually worry the forest engineer.

Wood Industries. Although we are not primarily concerned here with wood industries, it is necessary to give a brief review of them since in organizing the management of forests, the forester must know what the timber he produces will be used for, and what are the special requirements of the industries concerned as regards species of timber, dimensions and qualities.

Saw-milling. The basic wood industry is of course saw-milling. This may be undertaken by the agency owning and managing the forests, or the latter may prefer to hand it over to the timber industrialist, selling him the round timber either standing in the forest or felled and extracted. Where the forests are owned by the State, it has often been a controversial question as to whether the State should or should not itself mill the timber produced. There is certainly a better appreciation of the relation that should exist between what is grown and what it is wanted for, if the forest manager mills and markets his own timber, but it is a commonly held view that the qualifications required for the two activities are so different that few men are equally proficient at both. As so often, the solution is generally a compromise, the State milling a part only of its out-turn.

It may be said that in a general way, large-sized timber is more valuable than smaller material, but it does not follow that it is best on financial and other grounds to keep timber standing in the forest as long as possible. Rates of growth, which may be looked upon as rates of interest on capital, tend to fall off with increasing age, and old trees are increasingly exposed to deterioration from various causes such as heart-rot, causing loss in value per gross unit of volume. The nature of the material into which logs are sawn up is largely determined by the physical properties of the kind of timber in question and the purpose to which it is most suited. It is by no means the rule that the largest log is sawn into the largest pieces; thus, the outsized logs of the giant redwood may only be cut up into small roofing shingles. On the whole, the lighter timbers tend to be sawn into stock of moderate dimensions suitable for a wide range of uses, whilst the heavy hardwoods tend either to be used for purposes calling for considerable strength and so are sawn into bigger pieces such as beams, or they may be sawn in special ways aiming at revealing their frequently ornamental structure, as for instance for oak panelling.

Seasoning. As soon as a tree is felled the wood begins to dry out, the process being accelerated by any treatment that exposes a greater area of wood surface to the air, and continuing until equilibrium with the moisture in the surrounding air is reached. The moisture content of wood in an air-dry condition ordinarily lies between 15 per cent. and 20 per cent. of its oven-dry weight. During this drying process the wood shrinks to an extent differing in the longitudinal, radial and tangential directions, being least longitudinally. If a rectangular board or scantling is sawn from a fresh or wet log,

subsequent shrinkage may cause considerable distortion, the surfaces becoming no longer plane and parallel to a degree depending on the way the cuts have been orientated and the regularity of the growth. Internal strains often exist in the standing trunk and they may be released on sawing, this also leading to curved surfaces, and the same thing may happen when a larger piece of timber is further sawn up. Strains are also set up if drying takes place unevenly or too fast, and cause splitting and cracking. This behaviour is obviously a considerable disadvantage and all practicable steps have to be taken to minimize it. Experience has shown that it is considerably reduced if the logs are dried out gradually before being sawn and if freshly sawn material is similarly allowed to dry out under conditions that ensure slow and even loss of moisture. This can be done by stacking in such a way that air can circulate all through and the pieces lie flat and evenly supported. With hardwoods, air seasoning is done partly in the log, and partly by sawing into planks which are reassembled in the original order but separated by spacing sticks about one inch thick, set at intervals of two feet to three feet. Air seasoning is a slow business in the log and even after sawing, a matter of months for softwoods and a year or more for hardwoods, so means have been sought to hasten the drying. The obvious suggestion is to apply dry heat in kilns, but such treatment would result in serious cracking and splitting and 'case-hardening'. The solution is methods of kiln-seasoning in which moisture as well as temperature is closely regulated to a schedule worked out for each kind of timber with appropriate modifications for dimensions of material, etc. For almost all purposes, seasoned timber is vastly superior

to unseasoned and is absolutely essential for all high-class joinery, flooring and cabinet-making. The timber should be dried down to the moisture content that will be in balance with the air humidity to which it will subsequently be exposed in use, say 12 per cent. for indoor uses, or even 10 per cent. in heated space.

Wood Preservation and Fire-proofing. Some timbers both broad-leaved and coniferous, are naturally highly resistant to decay but many are *not* so, and if they are to be used where they are exposed to the weather or damp, they must be given some protection. The simplest and oldest method is to apply a coat of tar or paint, but this is only effective so long as the coat is absolutely intact and is of little use where the wood is in contact with the soil. To be made really resistant, the wood must be penetrated throughout with some substance which excludes rot and insects. By far the most generally used preservative is coal-tar creosote, the oily component of which also minimizes shrinkage and splitting; it is particularly suitable for railway sleepers and telegraph poles. A hot open-tank treatment suitably applied gives fair penetration, but pressure treatments are much more effective. In this way, non-durable woods such as spruce or sycamore can be made to last several times as long as without treatment, amply repaying the cost which may amount to about 1s. 3d. per cu. ft. The objections to creosote, apart from cost, are its inflammability and the fact that the surface cannot be painted. Many other preservatives have been tried and some are in regular use, e.g. copper sulphate and zinc chloride. These substances are cheaper and easier to apply and the wood can subsequently be painted: many are liable to leach out with water and so are unsuitable for outside use.

There are also many patent preservatives on the market, such as Tanalith and Cuprinol, which claim to fix the preservative in the wood.

For some uses, it is important to minimize the risk of fire which is associated with the use of timber. Various chemicals have been found which greatly increase the resistance to ignition when a flame impinges on the wood surface and slow down the rate of combustion. Ammonium phosphate and borate are among the best of these.

Veneers and Plywood. In relatively recent times, an increasing amount of timber has been prepared for use in a way very different from sawing ordinary 'dimension stock'. This development originated from the desire to make fuller use of specially ornamental characters of selected pieces, as with figured walnut. This can be done by cutting the piece into thin slices which can then be strengthened by glueing to a suitable backing. 'Sliced veneers', as such thin sheets are called, are commonly cut from many valuable timbers, particularly the ornamental burrs of various species. Means were subsequently discovered for the continuous peeling of a layer of wood by feeding a rotating log suitably prepared (usually by soaking or steaming) against a long fixed knife-edge. Such 'rotary veneers' are cut in increasingly large quantities from selected 'peeler' logs of such trees as the Douglas fir and beech which were formerly used exclusively as sawn timber.

Plywood. The main reason for the rapid development of this veneering industry has been for the subsequent use of the veneers for further processing into plywood. This in essence consists in glueing together three, five, or more veneers, alternate sheets being rotated through 90 degrees. This simple measure

imparts to the resultant plywood properties, particularly in strength and resistance to splitting, which are far superior to a single sheet of their combined thickness. By using a selected outermost ply over a core of less perfect plies of the same species or of lower grade species, a great economy of expensive material can be ensured with little or no loss in serviceability. A great deal of research has been done to find the most suitable glues for use in manufacturing plywood and in the conditions of temperature, moisture, and pressure to be applied during the process. Other materials such as asbestos or even metals may be incorporated for special purposes.

The most modern developments involve the application of high pressures and temperatures giving a new class of products better suited to specialized purposes. The chief glues now used are synthetic urea aldehyde and phenolic resins. Methods have also been found permitting the manufacture of the curved sheets required for such purposes as nautical and aircraft construction and some modern types of furniture. Plywood can now be used for speedboat hulls which call for exceptional lightness and strength, and parts of the fusilage of some aircraft are still being made of plywood. The basic principle of the process is pressing the assembled plywood by means of an air cushion into a mould before the glue has hardened. As an example of an important special use of plywood, it may be noted that India has to import annually (1944–45) tea chests worth £1½ million to supplement her own production.

The annual consumption of plywood in Britain is of the order of 500 million sq. ft. For maximum efficiency and economy, only the best logs can be used for making

rotary veneers and the supply of such logs is becoming short. Large quantities of veneer logs are imported into this country, mainly from the tropical forests of the colonies. Most of the best beech logs available are today similarly used, and latterly even birch and Scots pine have been pressed into service. Meanwhile methods and machines are being developed to make economic use of smaller logs.

Laminated Wood. Another development has been the wider adoption of the principle of building up or laminating relatively thin pieces of wood into composite units of larger dimensions. This process has the advantages of permitting the use of timber for purposes demanding lengths greater than can be obtained from single logs and of distributing and so reducing any weakness due to knots, etc. This in turn permits of the use of lighter structures than with ordinary timber, and consequent saving in size and weight. In this way, timber is frequently used in place of steel or light metals for the large trusses called for today for aircraft hangers, factory buildings, etc.

Matchwood. The cutting of veneers from certain timbers which are reasonably light and strong has led to the development of another important wood-using industry, viz. the match industry. Veneers are needed both for the splints and for the boxes, sometimes the same species being used for both purposes, and sometimes different species. This industry is being developed in one country after another and has frequently led to shortages of the kinds of timber most in demand, such as aspen in Sweden. The number of match splints that can be obtained from the timber of a single tree is naturally extremely large—it may be many millions. It has been calculated that where an excise duty is

levied on matches, the amount of revenue accruing from the duty may be as much as fifty times the price originally paid for the timber. As is generally known, *most of the two billion boxes of matches* used in Britain are imported, or at least made from imported timber, but there is no essential reason why this should continue to be so, for we can grow suitable timber at home.

Furniture. The manufacture of wooden furniture is another important industry. A good deal of it uses ordinary sawn material with the advantage of close utilization of small dimension stock, particularly short lengths which would often be wasted if not so used. Some kinds of timber used for furniture, such as beech, can be bent, usually after pre-treatment by steaming, into the desired shape, which is retained if drying is carried out before the removal of the constraining device. This process must be contrasted with the usual practice of the wheelwright who has to cut curved pieces out of rectilinear stock, mainly because the kinds of timber suitable for his work cannot be bent in this way. The manufacture of furniture also *frequently involves a certain amount of turnery work*, which we may next consider.

Turnery. The use of the lathe actuated by hand, by water power, or even the elasticity of a flexed sapling, is a very ancient discovery, still applied in all parts of the world as a small or cottage industry, though now mostly a big scale mechanized factory business. Turned wooden articles in widely ranging forms are in great demand, particularly in the textile industry where for various reasons wood is often preferred to other available materials for shuttles, reels, picking arms, etc. There is also a considerable demand for turned wooden

plates, bowls, rolling pins, etc. The timbers most used in Britain are birch and sycamore.

Cooperage. A rather smaller but not unimportant wood-using industry is cooperage, both dry and wet. The latter calls for the highest quality of timber of the few species particularly suited to the purpose, above all, oak. It is obvious that the barrels must remain watertight indefinitely and that the wood must not impart any trace of undesirable taste or colour to the liquid stored. The wood must also be exceptionally strong and resilient. Oak timber suitable for wet cooperage commands a price comparable only with that of good quality veneer timber.

Cleft-wood, etc. A considerable amount of wood is used locally as split or cleft material. This method of preparation carries certain advantages with it including cheapness. Oak and chestnut are good examples, being used mainly for fencing in a variety of forms. Chestnut pale fencing is finding an increasing market owing to its cheapness in comparison with available alternatives. The manufacture of sports goods is of considerable local importance, calling for timbers of exceptional strength and elasticity combined with lightness, e.g. ash and hickory. Considerable quantities of hazel and ash are still used for making sheep hurdles, though this minor industry has greatly dwindled.

Mechanical Pulpwood. Mention has already been made of the considerable extension in the use of wood after breaking it down to chips or even to its constituent fibres, and reconstituting them into a form more suitable for the purposes in view. If wet billets of wood are brought into contact with a rotating grindstone, they can be converted into a pulpy fibrous mass which by suitable appliances and treatment can

be spread in sheets of any required thickness, pressed and dried. In this way a range of materials from paper or cardboard, to the thicker fibreboard and wall-board may be obtained. Binding and bleaching materials may be added during the process if necessary, and a wide range of products turned out.

Fibreboard, etc. There has been a big increase in recent years in the use of reconstituted wood prepared in these ways, in the place of sawn material and ply-wood previously used for many of the same purposes. Although the cost is inevitably raised by the expenses of processing, there is some saving by the use of material of lower quality and smaller dimensions than are necessary to yield sawn material, and the resultant materials are easy to work and fit, and are often more suitable. Thus for use as an insulating material, a light fibreboard is definitely superior to solid wood. World production of fibreboard in 1950 was two million tons, an increase of 35 per cent. on the previous year: the U.S.A. produced 56 per cent. of the total amount, Sweden 14 per cent. and the U.K. only 1·7 per cent. or 35,000 tons.

Chemical Pulpwood. Wood can also be broken down to its component constituents by converting it into chips and digesting with certain chemicals, when the lignin component is dissolved, leaving the cellulose. About two-thirds of the total pulp production is chemical. The temperature, pressure, and duration of the treatment varies with the kind of wood, as require-ments are affected by the amount of tannins, resins, and colouring matter present, and to some extent the type of product desired. Softwoods are usually much easier to deal with than hardwoods and were formerly almost exclusively used, but it is now possible to treat

a wide variety of raw material and there are today pulp plants using eucalypts in Australia and bamboo in India. For most purposes bleaching of the pulp is necessary. After thorough washing, the suspended fibre is deposited in a thin sheet on a porous blanket from which it is picked up and dried, either in sheets (fibreboard) or rolls (paper). The pulp and paper industry has expanded enormously since the first plants for mechanical pulp were installed in Germany and Sweden about 1862, and for chemical pulp (sulphite) on both sides of the Atlantic about 1872. In 1950 world production of wood pulp amounted to 32 million tons and of newsprint 8·9 million tons, and the figures are still rising. The use of pulp for the manufacture of rayon has been mentioned.

Distillation. There is another way in which wood can be used as the raw material for industry, and that is by heating it in a closed retort and collecting the products which distil over. The residue of charcoal is itself in demand for many purposes, such as the manufacture of steel, the clarification of sugar and other organic substances, absorption of gases, manufacture of chemicals such as carbon disulphide, etc. The chief substances obtained from the distillate are wood alcohol and acetic acid, the latter usually being converted into another important solvent, acetone. The tarry parts of the distillate can also be used for certain purposes, but are not so useful as coal tar. Wood distillation has always been doubtful as a commercial proposition. Wood charcoal prepared this way or by burning in kilns of various types without collecting the volatile products is still used in preference to coke for the manufacture of the highest grades of steel, mainly

because the charcoal contains much less undesirable mineral impurities. There is of course considerable minor industry in most forest regions in burning charcoal for domestic use, particularly where alternative fuels are not available, and it is preferred to wood because it does not smoke when burning. When highly resinous wood is used, 'Stockholm tar' can also be collected as a still useful by-product.

Minor Products. Brief mention may be made of industries based on the minor forest products. Although the bark and fruit of certain trees provide the bulk of the tanning materials needed for the manufacture of leather, the raw materials from the forest are usually taken over by the leather industry without any preliminary processing. The other important product derived from bark is the cork from the cork oak which grows mainly in the Mediterranean countries, particularly Portugal and Algeria. The preparation of turpentine and rosin from the resin tapped from several species of pine is also a fairly large industry, mainly developed in the U.S.A. and France. The former country produced 13½ million gallons of turpentine by direct tapping in 1950–51, about two-thirds of the world's total, whilst the U.K. spent £5,000,000 on importing it. The collection of the resin from the tree is quite an important source of employment to the rural populations in the pine forests. It may be of interest to note that the blazes from which the resin flows yield annually about 1 lb. per blaze under the European method, and the blazes have to be freshened every week during the tapping season. The distillation process is very simple and is often carried out in or near the forests, more or less as a forestry operation.

Employment in Forestry and Forest Industry. It will have been deduced from this review of forest development and industry that the work involved must give a good deal of productive employment. Increasing mechanization has of course brought about some reduction in the number of men required for a given task, but the steady expansion of forestry and timber operations as a whole has more than compensated this. It used to be stated that forestry gave ten times the employment per hundred acres that grazing did, but only about a tenth of what is required for intensive agriculture. Of recent years, mechanization has very rapidly brought down the figure for agriculture whilst that for grazing has been little affected. Very roughly it may be said that one man is needed for every 80–150 acres of managed forest for its protection and silvicultural work, whilst about four more will be employed on felling, transport, and industry based on wood. These figures appear to hold equally for the more intensively managed forests of Europe and for the extensively managed forests of less developed areas where labour is less skilled and the work less highly organized.

Chapter VIII

SILVICULTURE: NATURAL REGENERATION

THE term silviculture is used to cover all the techniques of raising, tending, and regenerating a forest crop, and is directly comparable with the cognate terms horticulture and agriculture for garden and field crops respectively, though like these terms it is often used with a rather wider significance. It should be noted that silviculture is basically concerned with *crops* of trees, thus contrasting with arboriculture where the stress is on the care of the individual tree. The study of plant organisms in relation to their environment is covered by the now well-established term *ecology*, so that silviculture may correctly be described as applied forest ecology. A distinction is often drawn between the life history of the individual tree in relation to its surroundings, particularly its growth and development through all stages, which is covered by the term *autecology* and its *synecology* which deals with its relations with the rest of the plant community of which it is part.

The primary objects of silviculture are to give the trees retained on any site the best possible conditions of growth, and to ensure the replacement of old or inferior trees lost by death or felling, by new stock. Operations carried out to these ends are termed *tending* and *regeneration* respectively.

Natural Regeneration of Even-aged Crops. Historically it would be correct to commence our study of silvi-

culture with the application of tending operations to natural forests or semi-natural forests which have been modified by human activities, direct or indirect, including grazing, burning and the like. It will however be simpler to begin from the birth of a new crop, even though a natural forest crop only has a definite beginning after a major catastrophe destroying most or all of the old crop—a fire, a landslide, volcanic activities or a change of water level. Climax or virgin forest usually contains predominantly large and old trees even if there is a considerable range of age among them. Many may be overmature, growth vigour having fallen off and the timber decaying, though they may still be capable of providing good seed and of remaining alive for a considerable further period. If the land is to be used for timber production, it is clearly time to harvest the old crop and replace it by younger more vigorous growth. Experience has proved that it is usually possible through appropriate techniques to secure natural regeneration from seed falling from the old crop whether the latter is itself of natural or plantation origin. These techniques are concerned with method and rate of removal of the old crop, and treatment of the lower vegetation and soil. When a new crop is obtained in this way over a period of years that is short relatively to the age of the trees that are being felled and removed, the forester refers to it as an even-aged crop, ignoring the fact that strictly speaking it is not so, and may have an age range of even as much as fifty years. Such an even-aged crop is considered mature when the majority of the trees have reached a size suitable for the purposes for which they were being grown. In the case of trees for timber rather than poles, coppice, bark, etc., technical maturity usually falls

some time after the period of maximum rate of growth, but before there is any visible sign of old age. Actually, the maximum rate of wood production may be passed before the trees reach full seed production and before the best size of timber is attained. The techniques adopted for the natural regeneration on the even-aged plan vary considerably with species and conditions, and the chief types will next be reviewed.

Clear Felling. The simplest case is where the seed falling from the parent crop can germinate in its shade and persist for at least some time in sufficient quantity to develop into a new crop when the old one is felled, despite the damage inevitably done in felling and removing the latter. In such cases, provided that the seedling growth does not need overhead protection against sun or frost, the felling can be done in a single operation. There are also instances, as with the maritime pine growing on the sandy dunes of the Landes in S. France, where the mature crop can safely be clear-felled in a single operation, as a crop of new seedlings will develop the following season from seed already in the soil or released from the cones left with the felling debris on the ground.

Shelterwood Regeneration. More usually, this simple procedure is not possible, and the parent crop has to be removed gradually in a succession of fellings. The general principle involved is that the density of the initially more or less complete leafy canopy shall be gradually broken so that an increasing amount of light reaches the floor of the forest, making it possible for any existing groups of seedlings ('advance growth') to develop, and providing suitable conditions for the falling seed to germinate and the seedlings to establish themselves. As they grow, the seedlings need more

light which is provided by further fellings, and ultimately the stage is reached where the last of the parent trees can be removed. It will be noted that the regeneration receives protection against injurious physical agencies such as drought and frost during its early growth, and is only gradually exposed, getting 'hardened off' in the process. This method of natural regeneration is referred to as the *uniform* or *uniform shelterwood* method.

Group and Strip Regeneration. In some cases it has been found that better results can be obtained by local concentrations of the fellings rather than by making relatively uniform fellings throughout the crop. Thus small gaps may be made in the tree canopy, particularly over patches of regeneration, and these gaps and the regeneration gradually extended until they coalesce; this constitutes the *group* method. Or narrow regeneration strips may be cut with a specified orientation found by experience to be most successful, and these strips gradually widened. The conditions that would prevail along a strip cut in an east to west direction in the northern hemisphere may be further examined to bring out the factors involved. Seeds should reach the ground from the trees on either side of the initial strip provided it is not too wide. Sunlight will not reach the ground on the southern edge of the strip owing to the continuous shade of the adjoining trees. Not only will there be less light for a seedling starting along that edge, but it will be cooler and damper than along the northern edge where direct sunlight will strike and possibly cause considerable drying out. These differences are often quite enough to determine whether regeneration can be satisfactorily established or not. If, as may be the case with spruce on sites rather dry

for this shallow-rooted species, the conditions of the southern edge are necessary, the strip will be gradually widened by successive fellings along its southern edge and a wave of regeneration working in a southerly direction will be obtained.

An important practical point is the rate at which regeneration fellings can progress. It tends to be slow, so that a crop under regeneration may require a number of such strips advancing simultaneously to ensure completion of regeneration over a given area in a reasonable period of time. It should not be imagined that these strips will retain a regular outline since the rate of progress will depend on the almost invariably irregular development of regeneration. There are various elaborations of these general principles such as where the regeneration operations may advance in the form of wedges directed up wind into the mature crop, but it is unnecessary to go into further detail here. It must however be noted that wherever possible fellings have to be carried out in a way involving minimum damage to the new crop. This generally involves retaining the possibility of extracting the timber through the remaining old wood, though in Scandinavia felling and extraction can be done on the snow without harm to the regeneration. Hilly country presents difficulties as timber must usually be extracted down the slope, but a compromise is usually possible.

Control of Species Mixture. There is a complication that must be considered when we are dealing with a crop containing more than a single species of tree. In such cases there should always be a clear decision in mind as to the proportions of the several species that are desired in the new crop; these may be the same as or very different from those in the mature crop

under regeneration. It usually calls for very considerable skill and care to attain the desired objective. The ease with which regeneration of each constituent species is established under a canopy depends mainly on the seed supply reaching the ground and the relative ability to germinate and develop under the conditions prevailing. Those species that are most tolerant of shade, such as silver fir and beech, are at a considerable advantage over the less tolerant, or light demanders, such as oak and Scots pine or larch. If successive fellings are made as described above, the end result is likely to be an excessive predominance of the most shade tolerant (and possibly least valuable) species, and the procedure has to be modified to obviate this as far as possible. The main possibility of variation lies in the rate at which the overhead cover is removed, and some degree of regulation of its composition can be obtained by selective felling of the different species. Thus if there is a risk of getting too big a proportion of the shade-bearing species, the fellings will concentrate on these, thereby reducing the amount of seed falling as compared with that of the light demanders. The fellings will also be heavier and progress faster, so that the additional light may reach the forest floor before it is completely occupied by regeneration of the shade bearers that will preclude establishment of the light demanders.

These principles are illustrated by the following examples from broad-leaved forests. If it is desired to secure a proportion of oak trees in a mature beech forest containing scattered oak, the fellings will remove most of the beech whilst retaining the oak, and wherever oak regeneration is starting, it will be given more light. Even so, in most such cases, the beech will inevitably

predominate in the new crop, but the position can usually be remedied in the course of the later tending operations, which will favour the oak. Another example may be taken from the beech forests of Normandy. Here there is always some of the less valuable hornbeam mixed with the beech. Hornbeam seeds much more frequently and heavily than beech, and despite selective felling of the hornbeam during regeneration operations the seedling crop is often predominantly of hornbeam with only scattered beech. However, after some time, by repeated cutting out of the hornbeam, the proportion of beech standing in the developing crops is gradually increased to predominance.

Selection Felling. Turning now to regeneration in uneven-aged crops, the position is clearly very different, though several principles hold in common with the even-aged crop. As the crop consists of a more or less intimate mixture of ages and sizes—and usually species as well—felling of the mature trees will at most only make scattered gaps and often younger trees will already be present under the older. If the irregular structure is to be maintained, as is often desired, regeneration will have to be kept continuously in progress and trees reaching mature dimensions will be continuously removed making space for new growth. Tending operations will also have to be carried on continuously to secure good conditions of growth for the crop as a whole. In practice, these combined harvesting, tending and regeneration fellings, which are rather ambiguously termed 'selection' fellings, are not made every year but at regular intervals of five, ten or more years. The shade-bearing species will be even more strongly favoured—and that with less possibility of rectification —than under the methods described for even-aged

crops. Some help is however derived from the fact that there seems to be a tendency for trees not to regenerate very freely in the shade of their own kind. Norway spruce, which is only moderately shade tolerant, may be found regenerating under silver fir which is a very pronounced shade bearer, and *vice versa*. Whilst it is claimed that this selection system of working a forest has various advantages over the even-aged methods and there is a tendency to extend its use on the Continent, very few examples are to be seen in Britain. The claims made are that there is a fuller use of the growth potentialities of the site, which is also better protected and of higher amenity value, and that a greater proportion of the total wood production is in the larger and more valuable sizes, reducing the amount of small thinnings of low value and difficult to market. On the other hand, a higher standard of technical skill is demanded and periodic enumerations of the growing stock must be made to ensure maintenance of the correct growing stock and proportions of the several size classes, a difficulty that does not arise with even-aged crops grown on definite known areas.

Coppice Regeneration. Reference has already been made to the fact that many kinds of trees send up shoots from the stump or roots when the tree is cut down. This is often taken advantage of as a method of obtaining a new crop from coppice shoots or root suckers. In a general way, the older a tree becomes, the less readily it coppices, so the method is most suitable where wood is mostly wanted in small sizes. A very large proportion of the hardwood forests in W. Europe have at one time or another been worked and regenerated in this way as 'simple coppice' though it has frequently been the practice to retain some older stems

among the coppice to grow to larger dimensions as standards. *In the course of time the coppice stools get* old and decayed and must be replaced, either from natural seedlings or by planting. Where this principle of growing seedling and coppice trees on the same area is to be adopted as a permanent feature, special steps are necessary to secure and maintain a suitable number and distribution of standards. The numbers have to be limited or the development of the coppice will be too seriously hindered, and each time a coppice felling takes place some of the standards are felled and have to be replaced. Often there is some natural regeneration from seed so that there will be new saplings ('maidens') which can be retained for the purpose; if not, planting may be necessary. Ordinarily there are three or four age-classes of standards, with decreasing numbers in each successively older class, thus: 12, 6 and 3; or 16, 8, 4, 2. The standards are not necessarily of the same species as the coppice, but should not cast too heavy a shade, thus oak and ash but not beech. Sometimes coniferous standards are included. The coppice tends to be chestnut, oak, ash, and beech where hazel has not been brought in.

Chapter IX

ARTIFICIAL REGENERATION

REGENERATION by sowing or planting may be adopted for a variety of reasons, the chief of which is perhaps an inability to secure adequate natural regeneration in a reasonable time. Sowing and planting may be done to supplement natural seeding or as the main method of regeneration, sometimes under a shelterwood, but more usually after clear felling. The same techniques are mostly applicable to the creation of a new forest on land from which the original cover has long been denuded, or which perhaps has for whatever reason never hitherto carried forest; in this case we usually speak of *afforestation* which will be discussed separately in Chapter XII.

Collection of Seed. Artificial regeneration by sowing or planting starts with the collection of seed. This is a matter that often calls for considerable organization in view of the practical difficulties of collection and the irregular and sometimes infrequent seeding of many trees. Sometimes the seed can be collected from the ground which should be swept clean of prematurely fallen fruits, but it must often be collected from the standing trees by climbing or with the help of ladders. In view of the importance of collecting only seed of good genetic stocks, there is an increasing tendency to reserve selected good stands for seed collection, or even to raise special 'seed orchards' for the purpose, but this eminently desirable practice is still too recent to meet requirements, so that the forester usually has

to be content with collecting seed from the best suitable stands available to him.

Seed Extraction and Storage. Not only is it very important to ensure that the seed to be used is sound and mature, but care and special methods of storage may be involved. In the easier cases, all that is required is extraction of the seed from the cones or fruit and the cleaning and drying of the seed. Dry seed can usually be stored in sacks until the season for sowing without any special precautions other than securing dryness and ventilation. Fleshy seed such as oak and beech require much more care, as on the one hand they lose their vitality if they get too dry, and on the other will heat and spoil if damp or ill-ventilated. If stored in bulk, they must be repeatedly turned to prevent heating.

Seed Stratification. A common method of seed storage known as *stratification* copies nature in that the seed is kept buried between layers of sand or soil with good drainage. Not a few kinds of seed, for example maples, lime, hawthorn and Douglas fir, give much better results if stratified in this way than when otherwise stored. Some kinds of seed, chiefly those retained in hard woody fruits or provided with a thick more or less impervious seed coat, call for rather drastic treatments to stimulate germination. Thus with many leguminous seeds it is a helpful treatment to immerse them in boiling water and leave them to soak until it is cool. For teak, a process of alternate soaking and drying is among the treatments in use.

Post-maturation. There are a few species in which the seed requires a certain period for maturation before it is ready to germinate. Thus ash is not ordinarily ready to germinate until the second year after it falls. In contrast, there are some seed which normally

germinate immediately they fall, as with many fleshy seeds in the tropics and sessile oak in Europe, and others such as elm which very rapidly lose their viability and cannot be held over till the next season. Cold storage is being increasingly used for tree seed.

Preparation of Site for Sowing. It has next to be decided whether any special preparation of the site to be sown is necessary. Sometimes it is sufficient merely to broadcast the seed over the ground so that it reaches the soil in much the same way as would happen in nature. This method is perhaps most acceptable with small light seed available in large quantity, as the best conditions for germination involve only the lightest covering of soil or even none in damp spots. More usually however the method is very wasteful of seed, much of it being consumed by birds and rodents, and it may dry out too much for germination, so it is the usual practice to do a certain amount of soil preparation in patches or strips over the area to be sown, with an intensity that varies greatly with local conditions. Not infrequently there is a layer of raw humus over the surface of the soil too deep for the seedling roots to penetrate to the mineral soil. This layer may have to be removed or mixed with the upper soil by digging or ploughing. There may also be much weed growth on the forest floor to be eliminated before sowing. It has already been mentioned that it may be helpful to run a fire through the area under these conditions.

Season and Method of Sowing. Next comes a decision as to the kinds of seed to be used and the proportion in which they shall be mixed; the season of sowing may also be important. Autumn sowing may result in better development, but the seed are longer exposed to the depredations of insects, birds and rodents. Under

difficult conditions, it may be necessary to be ready to resow in case the first sowing fails for any reason—this is particularly common under conditions of inadequate and uncertain rainfall. It is important that seed shall be sown at the optimum depth in the soil. Too shallow sowing may result in drying out and poor germination; too deep sowing will cause delay and low germination. It is a common rule of thumb that seed shall be covered to a depth of approximately its own diameter. Large seed which can conveniently be handled individually are sometimes 'dibbled' directly into the soil without special preparation, particularly when it is a case of supplementing natural regeneration where seed-bearers or seedlings are deficient. Large-scale sowings are very usually done with mixtures of species, though in this country oak, which is almost the only species raised by sowing, is generally sown pure. Owing to the difficulty of handling mixtures of seeds of various sizes, the different species used in a mixture are usually sown separately. Commonly one or two species are sown throughout the length of the lines, broadcast or in drills, and the others are put out singly or in patches at suitable intervals along the lines. Some species may also be planted in. The main difficulty in dealing with such sowings is to find out how much help to give to the slower constituents, and only considerable experience can provide the answer.

Planting: Forest Nurseries. It may be said that whenever good results can be counted on with confidence, direct sowing is the best method for artificial restocking on account of its simplicity and cheapness. Unfortunately this is relatively rarely so, and the alternative of planting has to be adopted. If, then, the new stock is to be introduced in the form of young

plants, the first requirement is ordinarily the establishment of a forest nursery for raising them. It is however sometimes the practice to collect seedlings ('wildings') from parts of the forest where they are present in excess of local requirements, for use in the planting area. Quite good results have sometimes been obtained in this way, but usually the root system is poor compared with that obtained in a nursery, and there is usually more damage unavoidably done to these restricted roots in lifting them from the more compact soil.

Siting and Preparation of a Nursery. It is important that a forest nursery shall be carefully sited where the soil is well suited for the purpose, and micro-climatic factors, particularly freedom from frost, are favourable. The soil must not be too heavy or it will be cold, late, and difficult to work, and the lighter loams are to be preferred. Easterly aspects are to be avoided as any frost danger is particularly liable to be accentuated by rapid thawing by the morning sun. Hot southerly and south-westerly aspects are inadvisable because of their excessive insolation and dryness. In preparing the nursery for use, the soil has to be very thoroughly worked to a good tilth and kept in that condition. Particular attention has to be paid to the maintenance of fertility over a succession of crops and this is not always easy. Organic manures are usually favoured though liable to introduce objectionable weed growth. Forest leaf-mould is the best in this respect but composts of various types are much used. It has been found that a soil which is good for agricultural purposes is not necessarily good for a forest nursery. This particularly applies to the raising of coniferous seedlings, which generally do best when the soil is definitely more acid than is ideal for field crops. The nursery is usually

divided up into raised beds about 3 to 4 ft. wide (so that they can be reached for weeding from both sides), and of varying length, 30 to 40 ft. being common. It is often necessary to provide shades to protect the beds from excessive insolation and drying out, or against frost. Usually the shades are of a type which can easily be spread or removed as required from time to time. Facilities for watering may also be necessary, the watering being done by percolation (rarely by flooding) or by spraying from watering cans or overhead sprinklers. Nurseries are usually sheltered from strong wind by being surrounded and divided up into blocks by good hedges, Lawson's cypress being a favourite for this purpose.

Sowing in the Nursery. The seed is sown broadcast or in drills, various methods and devices being in use to meet varying requirements. In Britain, conifer seed should be sown early in April and broad-leaved trees mostly soon after collection. Considerable importance is attached to securing the right depth and nature of covering for the seed after it is sown, particularly for the smaller kinds. By the use of a suitable type of covering, any tendency in the surface soil to cake may be prevented, quicker and more regular germination is secured, and the difficult early weeding is facilitated. Clean coarse sands are usually found to be the most suitable covering material. It is always a problem to keep weed growth to a minimum as many tree seedlings are very small and delicate in their early stages and weeding is a costly operation. The first measure is to see that as little weed seed as possible remains in the soil at the time of sowing and to keep the nursery and its surround clear of weeds. Special measures are also adopted such as partially sterilizing the soil with a

blow lamp, formalin, or even steam. The blow lamp can sometimes effectively be used after sowing to kill off the more quickly germinating weeds before the tree seedlings have emerged. Chemical selective weed killers have also their place and appear likely to be more used in future.

Lining-out. Very generally in temperate regions, the seedlings at the end of their first year of growth are not large enough to be suitable for planting out in the forest. If they are kept in the original seed bed for a second year they are liable to suffer from crowding and do not develop so well as when moved to a new bed for the second season of growth. To meet this objection, the practice of 'transplanting' or 'lining-out' is very generally adopted. The plants are lifted during the rest period, October to April, in suitable weather, as soon as they are large enough to handle (which may sometimes be only after two seasons) and replanted at regular intervals in freshly prepared ground. It is of vital importance that the roots of the lifted seedlings shall not be allowed to dry out before they are replanted. Inferior seedlings which are termed 'culls' are rejected. A common spacing is 2 in. by 10 in., but what is advisable varies considerably with the stock concerned. It is important that these transplants shall be well firmed into the soil with the roots in as natural a position as possible. It is still almost entirely done by hand though attempts have been made to mechanize it using machinery adapted from that used for field crops. The chief difficulties are the small size of plant used, the close spacing needed, and the importance of correct position of the roots. Mention must be made of the *planting board* commonly used in this work. It is a device consisting essentially of a narrow board about

10 ft. long notched at the desired planting intervals. To this board is hinged a light lathe which can be swung over it after a seedling has been set in the appropriate position in each notch. The board carrying the seedlings is then placed against a prepared face of soil in such a way that the plants are all at the proper level and the roots are in their proper position. Soil is then thrown against the roots and firmed in position before the board is removed and the soil shaped for the next line. The work can be done very quickly by an experienced team, and a team of four should line out 20,000 plants in a day. The main purpose of lining-out is to get a good well-branched root system in preparation for the move to the forest site because experience has shown that subsequent casualties are much reduced, particularly in species such as oak and Corsican pine which tend otherwise to develop only a poor root system limited to a deep growing taproot and a few feebly branched laterals likely to be broken in lifting. Of course, transplants are much more expensive than seedlings, as is illustrated by the fact that the price currently quoted for seedling stock is 45s. per thousand as compared with 125s. for two-year-old transplants of larch. The age of planting stock is usually expressed as the number of seasons spent as a seedling *plus* the number spent as a transplant, thus 1 + 2 stock means that the plants have spent one year in the seedling bed followed by two years in the transplant lines, whilst 1 + 1 + 1 implies that though again three years old, they have been transplanted twice. Plants taken direct from the seed-beds are described as 1 + 0 or 2 + 0.

The seedlings may remain for one or sometimes two years in their new position before being lifted again for

planting out in the forest. During this period they have to be kept weeded but do not require much other attention. Attempts are also being made with some degree of success to mechanize this weeding operation, using tractors which can straddle the beds. The scale on which nursery work is required is illustrated by the fact that the British Forestry Commission planted out 115 million seedlings and transplants in its operations during the year 1951.

Vegetative Propagation. Although planting stock is very predominantly raised from seed, a limited amount is raised by vegetative propagation of stem or branch cuttings, particularly for certain species, above all for poplars which mostly strike root with exceptional ease. Of recent years, there has been some development of this method with more difficult species with the help of chemical stimulants to rooting, notably the substances of the hormone type, e.g. indolyl acetic acid. One of the main reasons for wishing to raise stock this way is that a considerable number of individuals can be obtained from any single plant which for whatever reason is of special interest. Apart from delays and difficulties that might be involved in waiting for seed, it may be desired, as in the propagation of hybrids, to avoid the use of seed as pollination may have involved mingling with another stock. Other methods of vegetative multiplication of selected stock are *grafting* and *budding*. These techniques do not of course increase the total number of plants available for use, but they are valuable for multiplying a selected stock or strain.

As an illustration of a typical technique used for cuttings, some further details may be given for poplars. A common method is to take lengths about 12 in. long from the current year's shoot of a strongly growing

branch, cutting back the 2 in. to 3 in. immature wood at the tip. This is done in autumn or winter. The cuttings are inserted obliquely in the soil, buried except for the top bud, at about 12 in. by 9 in. spacing. After the first growing season they are lifted, the stems cut back to about 3 in., and the rooted cuttings replanted in good manured ground at 3 ft. by 2 ft. They are left to grow two more seasons before planting out, being kept to one shoot and free of side branches, and should reach 8 to 10 ft. in height.

Temporary Nurseries. Although the majority of nursery stock used is raised in more or less permanent nurseries, it is often found preferable to make temporary nurseries on or near the planting site where the stock will be planted out. Even better results than those obtainable in permanent nurseries are sometimes secured on a new site; weed and insect troubles are at a minimum and the new soil may be more fertile or respond well to composting. Such temporary nurseries are being used on a considerable scale in some parts of Britain. Temporary nurseries are often used for lining-out seedlings raised in a permanent one.

Spacing in Plantations. Spacing may vary from as close as 4ft. by 2 ft. for oak seedlings, to 5 ft. by 5 ft. for Douglas fir, or to very much wider intervals, e.g. 20 ft. by 24 ft. or even wider, as typical for poplars and cricket-bat willows. Sometimes, as with sowings, lines are preferred and may be anything from 5 ft. to 66 ft. apart.

Preparation of Planting Site. As with sowing, so with planting, some degree of soil preparation may be needed on the plantation area. Perhaps the most important considerations are the removal of weed growth and the working up of the soil to a good tilth. The commonest

procedure, at least in Britain, is to prepare in this way patches of ground spaced out at distances appropriate for species and conditions. The soil preparation for line planting may be done by horse or tractor-drawn plough, but for spot planting is still almost universally done by hand as a really suitable machine is not yet available. This work may be done at the time of, or shortly before, the actual planting work begins, but it is sometimes advantageous to do it earlier as a period of weathering of the soil may be beneficial. Where there is much refuse on the planting site, it may be advantageous to burn it off in heaps or broadcast before beginning work, indeed the step seems to be essential to success under some conditions, as in pine forests in Norway. Not only does the burn remove the debris and destroy weed seed and excess of raw humus, but it provides a dressing of stimulating wood ash and often exerts a favourable influence on the condition of the soil. On wet soils, drainage may be an essential preliminary: in the case of peat, the turf removed may be used to form a raised site on which the plant may be started.

Choice of Species. Mistakes are frequently made by using in plantations species which are not suitable for the soil and other factors of the planting area. The requirements of the various species should be known from a study of their ecology in natural forests. Frequently the pre-existing vegetation, even if not including the species in question, can provide good indications as to what can be planted with reasonable prospect of success, but the opportunity is frequently missed, particularly where burning is a customary preliminary to planting. The presence of certain plants on a site has often been found to reflect the soil conditions and suggest what might safely be planted. This

subject has been reviewed from the U.K. standpoint by M. L. Anderson. As an example, a site on which *Brachypodium* grasses predominate should be suitable for Japanese larch or beech, whilst on an *Erica tetralix* type, pines will be the only safe species to use.

Season of Planting. It is of the greatest importance that the actual planting work shall be done early in the season to provide the plants with the maximum growing time during their first growth period. This should ensure that they are well rooted and established before the advent of the unfavourable season. This point becomes the more important as the site is more unfavourable, particularly in dry regions. In Britain, we sometimes have the choice between autumn and spring planting. Whilst it is usual to plant conifers in spring, better results are often obtained with hardwoods with autumn planting. The reason for the difference may be related to the fact that root activity continues in hardwoods at lower soil temperatures than in softwoods.

Mixtures. For a variety of reasons, plantations are often made with a mixture of two or more species.

Arrangement of Mixtures. When planting a mixture, there are various ways in which the different species can be arranged. The simplest method is to have separate lines for each species; the relative number of lines of each and their position in relation to the lines of the other species has to be decided in each case, and this is not easy. Not infrequently strips of two or more adjoining lines of the same species are adopted. Even when every care is taken to allow for probable different rates of growth and different tolerance of shade, it is rare that such an arrangement develops uniformly or as it was expected to do. The obvious suggestion that

the difficulty might be overcome by a regular alternation of the species in the rows is not acceptable, for in fact it only results in the reorientation of the rows to a diagonal position. An alternative suggestion is to plant groups of some of the species in a matrix formed by one or more others. This has fairly often been done with groups of oak planted in a matrix of larch, etc. Once again the subsequent guidance of development in the desired direction has proved difficult, though the early return from larch thinnings in the case quoted is welcome. Very frequently mixed plantations have not received the careful tending necessary to carry out the original intention and the several species have to a considerable extent been left to fight it out among themselves, usually with the result that most of the slower and less shade tolerant are killed out. It is relatively rare to come across a really successful mixed plantation of any age.

Planting Out. Most planting is done with naked rooted transplants. It is extremely important that the roots shall be as intact as possible and shall not be permitted to dry out between the time of lifting and the time they are once again buried in the soil; nor must the transplants be so tightly packed for transport that there is a risk of heating and decay. It is a common practice to puddle the roots of the newly lifted plants in wet mud to give them a protective film of fine soil. The next point requiring attention is that the roots shall be placed in as natural a position as possible when the transplant is planted out. At the same time it is not a practical proposition in big scale forestry to spend the time on each plant that would be given to it in a park or garden, though an approximation to this is attempted in what is termed 'pit planting'. The commonest

method in Britain is to 'notch' the young plant into the soil. This is done by inserting the planting spade twice into the soil to make an L-shaped cut and open up a notch into which the roots can be inserted with a minimum of doubling up. The soil is then firmed against the roots, usually with the foot, reclosing the notch. Sometimes a T-shaped notch is preferred. Another detail to which attention must be given is that the level of the plant must be the same as it was in the nursery, neither higher nor lower. In peaty ground, the transplant (usually a spruce) may be planted into a turf above the general level of the ground to improve drainage and aeration of the roots; the turves are obtained in the cutting of drains.

Mechanized Planting. Where topography and soil permit, it is possible to consider mechanizing the planting operation and a number of machines are on the market. The necessary conditions are however rarely present on areas available for afforestation.

Size of Plant. The best size of plant to use depends again on species and conditions. As a general rule, it can be said that the smaller the better provided successful establishment can be guaranteed, for all costs will be at a minimum. Conditions however are frequently such that a moderately large plant must be used to make it safe against the weed competition it will meet during its establishment period. The extra weeding necessary to get up unduly small plants may easily cancel out the initial economy obtained by using them. Large plants are more likely to be damaged in handling and to fail to survive adverse conditions before they are sufficiently well established in their new site, but under favourable conditions, quite large transplants can be used to advantage, particularly where weed

growth is a serious threat. The bulk of the coniferous planting is done with transplants 6 in. to 8 in. high, rather less for pines. Oak and beech are either planted as seedlings about 4 in. to 6 in. high or as larger transplants about 12 in. Where large transplants are used, it is sometimes necessary to prune them back or partially to strip the leaves, to reduce the loss of moisture before the roots have re-established sufficient contacts with the soil to supply the needs of the above-ground portions. The use of large transplants, widely spaced, has already been noted as customary with poplars.

Stump Planting. A variation of the general practice which has spread very widely in tropical forestry calls for mention. This is the use of 'root and shoot cuttings' or 'stumps'. These are unbranched sticks consisting of one or two inches of stem and six to twelve inches of unbranched taproot. These stumps are made from nursery stock of appropriate size (they should be ½ to ⅝ in. diameter) and are replanted with the same precautions against damage and incorrect position in the soil as ordinary transplants. They are less subject to drying out during handling, are simple and cheap to plant, and they usually give a bigger stronger shoot during the first growing season than is obtainable from seed or from an ordinary transplant. This method is very generally used for teak and is applicable to a great many other species.

Planting with Containers, etc. Some seedlings are very difficult to handle with naked roots, and under severe conditions, avoidance of breaking the contact between the fine roots and the soil when planting is essential to success. In such cases, plants may be raised in individual containers made of various materials, such as pottery, tarred paper, bamboo, or green leaves,

and planted out with the included soil, with or without removal of the container. Sometimes (as often with *Eucalyptus*) the seedlings are raised in blocks of moss or peat in a similar way.

Cuttings. Stem and branch cuttings are sometimes used for direct planting. Poplar has already been mentioned as often planted this way, but on the whole does best as stumped transplants. *Tamarix* in semi-desert regions provides a tropical example. Root cuttings may also be used in some species.

Taungya. A variation on the normal technique of plantations involves the more intensive clearing and preparation of the planting site and the raising of the tree crops in conjunction with agricultural crops. This method was developed as a remedy for the forest destruction brought about by the primitive practice of shifting cultivation prevalent in some forest regions. The normal procedure of the shifting farmer as we saw in Chapter I is to cut down an area of forest sufficient for his purposes and burn the felled material with as hot a fire as possible. He then sows his field crop with or without soil working. The crops grow vigorously on the virgin and largely weed-free soil, but deterioration and weed invasion take place so rapidly that after only one or two years he moves to a fresh plot of forest. The abandoned plots gradually revert to forest of a sort, but before full development can be reached the area may again be subjected to the same treatment. The idea was conceived that valuable forest trees might be introduced into the abandoned plot by sowing or planting. Although somewhat similar practices were followed in Europe, the method is generally known as *taungya* from the Burmese name for such clearings, teak being the species most used. The general principles

involved have been considerably developed and adapted to different conditions, so that the area regenerated by this method had reached about eight thousand acres annually in India alone before the war. Agriculturists have even been brought into forests where shifting cultivation was not normally done, in order to get planting done this way.

Weeding Plantations. Very soon after the seed has germinated in forest sowings, or nursery stock has been planted out, the young plants have to be assisted against competition by weed growth, though requirements differ greatly for different species. Particularly in the case of sowings, timely and efficient weeding may be very vital to success, but it is possible to overweed, thereby disturbing the roots of the tree seedlings and exposing them to excessive insolation. Grass growth appears to have an exceptionally adverse effect on tree growth, though the precise reasons for this are still uncertain and it is difficult to exclude. During the first growing season, at least one thorough weeding is almost always necessary, and it is common, particularly under damp conditions, to have to repeat the operation two or three times. Further weeding is very ordinarily necessary in the second year, after which the new crop may be able to look after itself. With slow growing species and vigorous weed growth, such for example as one usually gets with oak on a bracken site, weeding may have to be repeated at intervals for as much as ten years, putting up costs considerably. There is an extremely wide range of requirements in this matter and it becomes a problem in each case to determine the right procedure for optimum results.

Protection. During this period of early growth, plantations very ordinarily have to be protected from

other forms of damage besides weeds. Obviously special care will be needed to exclude fire even where it will do no significant harm at a later stage. Protection from grazing may have to be effected by the erection of cattle and sheep fences which are expensive, and the erection of the deer-proof fences sometimes necessary is much more so. In Britain, we are very ordinarily forced to net against rabbits and hares. The current (1952) cost of erecting rabbit netting is roughly 3s. per yard, which works out to about £20 per acre, depending on the size and shape of the enclosure.

Insects. Young trees are also subject to damage by various insects. Coniferous plantations are particularly subject to attacks from pine weevils which may be quite serious. These insects breed mainly in the stumps of felled pine trees and as adults feed on the bark of the young plants, killing them by girdling. To minimize this risk, special steps are taken to trap and destroy any insects present, and it is necessary to postpone planting in the vicinity of a felled area for about five years until the stumps are no longer suitable for breeding.

Cleaning. Even after the young plantation is advanced enough to be safe from the competing ground vegetation, there may be a good deal of unwanted woody growth coming up among the trees, and its removal together with any climbers that may be present is usually termed a *cleaning*. Examples commonly met with in Britain are sallow, birch, and honeysuckle. This operation becomes specially important and may have to be repeated at frequent intervals in damp fertile sites, particularly in warm countries where there are always many kinds of fast growing weed-trees and climbers. There has been some reaction of recent

years with regard to the extent to which it is desirable to eliminate all this competing growth. In fact, there is increasing evidence that it is preferable to keep at least some of it in what would otherwise be too pure a crop of the one or few planted species. Thus it was formerly the practice to cut out all birch which sprang up in coniferous plantations, whereas it is now thought that at least some should be retained on account of its favourable effect on the soil, as it tends to counteract the undue acidification brought about by the coniferous leaf fall. Somewhat similar is the case for the retention of some admixture of beech and other 'soil improvers' among oak.

Chapter X

TENDING AND SILVICULTURAL SYSTEMS

WITH the cleaning operations, the new crop, whether from natural or artificial regeneration, may be considered as established. The parent crop will have been harvested except perhaps for a limited number of trees retained for the production of extra large timber, or for amenity purposes, and we are concerned almost entirely with caring for the new young crop to provide it with optimum conditions for development. The operations involved are collectively termed *tending*, and the selective removal of some of the trees for the benefit of the others, i.e. *thinning*, is the chief of them. When dealing with uneven-aged crops, the tending operations merge with the harvesting and regeneration, but the same principles are involved.

Thinnings. By the time the cleanings have been carried out in the more or less even-aged young crop, the crowns of adjoining trees should have closed up and formed an almost complete cover to the soil. At this point—and perhaps even before this—competition between the individual trees sets in, and it becomes necessary to take a hand in directing the outcome of this competition. The less desirable individuals must gradually be removed to provide adequate growing space for the better ones retained, and attention will be needed as before to the maintenance of the best proportions of the species present. The exact details of these thinnings will vary with species and mixtures,

and the class of timber aimed at. It cannot be said that foresters are all agreed on the time, severity and frequence of thinnings, though the necessity for them is undisputed. There is some difficulty in providing a sufficiently clear description of how any particular type of thinning shall be carried out though several methods have been suggested.

Tree Classification. Until recently the general practice has been to classify the trees found in more or less regular plantations or natural regeneration according to the relative position of the tree in the general crown canopy. Thus the *dominant* trees are those that have attained the full height of the crop and have relatively large crowns, whilst at the other extreme, the *suppressed* trees are overtopped by the dominants and have small restricted crowns. Between these two extremes come all the remaining trees further classified as *co-dominant* and *sub-dominant* or *dominated*, which do not attain the full height of the crop and are variously restricted in their development by the neighbouring dominants. It is also further possible to classify the *boles* or stems of the trees according to their straightness, freedom from defects, and general quality as potential timber. If the trees in a crop are classified in this way, it becomes possible to describe a particular mode of thinning as removing trees of particular classes.

For research purposes at least, a more or less standardized classification of thinnings as light, moderate, heavy, and very heavy has long been in use. The modern tendency has been to advance considerably towards heavier thinnings than were formerly customary. In fact, of recent years the view has been put forward that the proper time for thinning is not after competition has visibly set in to the visible

detriment of the crop, but before this stage is reached. If this is done, it leads to what would ordinarily be considered an excessive opening up of the canopy, making pruning essential and often exposing the soil to an undesirable extent. It may however prove to be a sound method where conditions are favourable, as in the pine and wattle plantations of S. Africa where the method was originated by I. Craib, with whose name it is associated.

Execution of Thinnings. These thinnings ordinarily begin with the removal of the suppressed and dominated trees, encroaching only gradually, if at all, on the dominant class. This type of thinning is known as *low thinning* in contrast with a *high thinning* or *crown thinning* which derives from a different approach. In crown thinning, the principle involved is to select dominant trees which it is desired to favour as the most promising in the crop, and to promote their development by the removal of such less satisfactory neighbouring trees as are hindering them. The trees removed will thus be mainly co- and sub-dominants and even some of the less satisfactory dominants, rather than the suppressed and dominated trees which remain to help cover the soil and possibly to replace casualties. In all cases, a certain number of coarsely branched trees which have markedly outgrown their neighbours and are known as *wolf-trees* are also removed.

Thinnings by Number or Spacing. There is another mainly statistical approach possible by determining through experiment the optimum number of stems per acre, or if preferred, the average spacing, in a crop of specified mean diameter or height; age is sometimes but ill-advisedly used as the criterion. The actual thinning in this case will tend to be carried out rather

like a crown thinning, by selecting the trees to be retained rather than those to be removed. In all cases some sort of compromise is unavoidable between what is desirable from the point of view of tree form, and what is needed to ensure acceptably even spacing. To give a good outturn in clean timber, it is often desirable or even necessary to keep the crop rather denser than would otherwise be done, to take advantage of the 'drawing up' effect of a close crop and to shade out as soon as possible the lower branches which will otherwise form large knots in the timber. Requirements in this respect vary greatly for individual species and even for the same species growing under different conditions, and only accumulated experience can provide a guide to what is best.

First Thinnings. Shortly before a thinning is due, it is usual in Britain (though rarely elsewhere) to remove the lower dry branches to head height from many or even all the trees to facilitate movement and incidentally to reduce fire riske: inspection 'racks' may have been cut even earlier. A sharp curved pruning saw is recommended as much preferable to a billhook. Thinnings are ordinarily commenced in most coniferous crops when the stems reach about 25 to 30 ft. in height, Douglas fir 35 ft. and Sitka spruce 40 ft., which happens at ages of 20 years to 25 years on average sites. It is recommended to commence thinning oak and beech at about the same height of 30 ft. which is reached at a much later age, about 40 years for oak. Teak must usually be thinned when five years old on average sites and at four years on good ones. On Craib's method, thinnings will begin earlier in all cases.

Thinning Cycle. The interval allowed to elapse between successive thinnings is important. Generally

the lighter the thinning, the more frequently should it be done and the shorter the cycle. Though frequent light thinnings are usually the theoretical ideal, they are not always possible, so that five years for young crops and ten years for older ones are still common.

Pruning. If relatively heavy thinnings are made to obtain rapid growth in diameter, the branches will inevitably become coarser and persist longer than in a dense crop. This defect may be remedied by pruning back to the main stem. The work has to be very carefully done and may expose the tree to some risk of fungus infection, but the cost may be amply covered by the increased value per unit volume of the knot-free timber subsequently laid down. Such pruning of a proportion of the best trees in a young crop is becoming fairly widely adopted at least for some species such as Douglas fir. The season in which the work is done may be important from the point of view of risk of fungus infection as has clearly been demonstrated in Holland for Japanese larch which should be pruned, not in the dormant season which one would tend to think best, but in the growing season when the wound is most quickly covered over.

Thinning Yield. The significance of these thinning operations from the timber production point of view is indicated by the fact that about one-third of the total yield of a plantation is commonly derived as *intermediate yield* from thinnings, and the remaining two-thirds from the final crop at maturity, but the proportion may be as high as one-half.

Tending Irregular Crops. Although the same general principle applies to irregular crops as to even-aged crops, that trees retained after a tending operation or thinning shall as far as possible be given optimum

conditions for growth and development as a crop, its application to uneven-aged crops is naturally much more difficult. In addition to all the considerations affecting competition between trees of about the same age and size, we have the problem of regulating the balance between the different age groups—or, in practice, size groups—as we have to assume rough agreement between age and size. The real difficulty lies in the fact that it is extremely hard to decide what the balance is that we are trying to attain. Theoretically, the answer is straightforward that the ideal is characterized by that age (or size) class structure which ensures in perpetuity the maximum production in the most valuable form. Even so, the same annual production may be possible from denser or more open crops: the standing crop represents the capital of the forest, and for best percentage returns, this capital should be no higher than necessary, so we have to decide what shall be considered the optimum volume per acre at which to aim. In practice one can only guess what the ideal volume and structure are likely to be, and carry out trials covering at least a representative range of sites. Another practical difficulty is that as one cannot make a reliable ocular estimate, extensive enumerations must be carried out at relatively short intervals. Having determined the present composition of a crop and the ideal structure, we can then carry out a combined harvesting of mature trees and selective thinning of the younger classes, falling most heavily on those size classes which the enumerations show are present in excessive proportion. Of course, attention must also be paid to the smaller regeneration: if it is adequate in amount, the fellings must give it enough light and space to develop, whilst if it is deficient, they must

provide conditions which will permit and encourage new seedling growth (called *recruitment*).

Where the irregular forest has not hitherto been given regular attention, the first operation will remove all definitely injurious growth such as woody climbers and diseased trees likely to spread infection. It will also deal with trees which are economically valueless either from being of unsaleable species or from decay and other defects, removing them in favour of more promising growth of the better species, but retaining them where they are needed for covering the ground or other silvicultural reasons. Operations of this kind are usually termed *improvement fellings*, or if little or no saleable material is obtained, *cultural operations*. Removal of undesirable trees is often done by *girdling* which consists in removing a ring of bark from the whole circumference of the bole at a convenient height from the ground, cutting into the outer wood at the same time to a depth that experience shows is necessary to kill the species of tree in question. Solutions of poisons are often poured on to the cut surface to hasten death, arsenic preparations including the proprietory 'Atlas' being commonly used. The advantages of girdling over felling are less cost, less damage to the surrounding crop, and the gradual instead of sudden change in the light conditions. Two or three cycles of cultural operations of this kind at intervals of five or ten years may result in very considerable improvement at relatively little cost.

Silvicultural Systems. The foregoing account of the life history of a tree crop throughout its course, makes it clear that a considerable range of possibilities is open to the forester planning the management of his forests. The method of regeneration is the predominant con-

sideration as it determines to a considerable extent the whole future treatment, and the structure and appearance of the stands. Foresters recognize a number of methods, each complete in itself, which they term *silvicultural systems*. Each system adopts a definite method of regeneration, but has also to take into account the subsequent tending and other operations throughout the life of a crop. Each system will give crops of different recognizable form and structure.

The main systems are the following: Firstly, those systems that are dependent on seedling regeneration are differentiated as *High forest* systems from the *Coppice* systems which depend mainly on coppice regeneration. The chief forms of the latter are *Simple coppice* and *Coppice with standards* which have already been mentioned (p. 125); *Selection coppice* differs from simple coppice in that all the shoots are not cut at the same time, but only a selection of them, usually such as have reached a certain marketable size.

Under the coppice with standards system, as each coppice felling is made when the shoots have reached the age fixed for cutting, the mature standards are felled and a thinning is made among the younger ones to keep their number, distribution and proportions at the optimum. A new class is added from the new saplings ('maidens') which may have come up. If there are no suitable maiden trees, selected coppice shoots are retained ('stored') in their place, or planting will have to be done. Standards of two or more ages will thus always be present, their number being regulated to figures found by experience to be most suitable, say 20 to 30 per acre.

The high forest systems are divided into the *Selection* system with all ages present on the unit area of

management, and the *Regular* or *Even-aged* systems where regeneration is completed in a more or less definite period of time shorter than the rotation age—usually a definite fraction of it. A variation on the selection system is the *Group selection* system in which fellings are made by groups rather than by single trees.

The main divisions of the Even-aged systems are based on the methods of regeneration which have already been mentioned, giving the *Clear felling*, the *Uniform shelterwood*, *Group*, *Strip* and *Wedge* systems. Each of these is readily recognized during the regeneration phase, but the differences tend to be lost as the regenerated crop develops further through middle age to maturity.

It is sometimes the practice to retain some trees at the time of regeneration for a further period to provide a certain amount of extra big timber or for other reasons. This gives a *two-storied high forest*, but it is only when such trees are retained throughout the second rotation that the requirements are filled for recognition of a separate silvicultural system.

Apart from the relative efficiency of the different methods of regeneration involved, these different systems vary from one another in respect of the types of material they yield, the proportions of the different size classes, and the quality of the timber produced. They also differ in ease of execution, supervision, and extraction of produce, involving varying risks of damage to the succeeding crop. All these factors have to be taken into account when deciding what is the best system to adopt for any forest or group of forests. Agreement has not been reached as to their relative merits from the point of view of total production from a given area, but it is unlikely that any differences that

may exist are large enough to be important. On the other hand, there are significant differences in the average size and quality of the timber produced, a matter in which the thinning technique adopted also plays a part. In a general way, the aim will be to secure the biggest possible proportion of the total yield in the form of high-priced material. It is generally accepted that the selection system can give a larger proportion of the total yield in material of the bigger dimensions, but opinion differs as to whether some loss of quality may not be involved.

Chapter XI

GROWTH OF CROPS: MENSURATION AND MANAGEMENT: FOREST ECONOMICS

Increment. Throughout the life of a forest crop, it is necessary for the forester to know how much wood it is producing annually. This rate of growth is technically termed the '*increment*'. When reasonably free from competition, the rate of growth of a tree in height tends to be slow just at first as a seedling and then to increase rapidly to a maximum in youth; it then gradually falls off again and practically stops at maturity. The average height reached by mature trees has been found to be the best single indication of the fertility of a site, and is generally so used. Much the same holds for the height development of even-aged crops of trees.

Girth and Volume Increment. Volume increment may continue long after the full height has been reached, but does not accurately reflect *value* increment, because in a general way the value per unit volume increases with size and age of the trunk provided it remains free from decay and is not disproportionately knotty. A crop may be increasing in value even if it is falling in volume through felling or natural casualties. The thinning regime to which a forest is subjected exerts a considerable influence on the distribution of the volume between the different sizes of timber which can be obtained. In forest practice, there are two ways in which increment is measured, viz. *current annual increment* (C.A.I.), which is the growth taking place

in the year of measurement, or more ordinarily the average rate over the last short period of years (say ten years), and the *mean annual increment* (M.A.I.), which is the average over the whole life of the tree or crop, i.e. the total volume produced to date divided by the age. Both increments increase rapidly in youth, the current annual the more so. Later on, the value of the current annual increment passes its peak value and begins to fall again, whilst the mean annual increment is still rising, and at a certain age the two types of increment will be equal. This age at which M.A.I. culminates is of importance in determining the *rotation* to which forests shall be grown, as if they are kept longer, average volume production falls off, though it may be compensated, as we have seen, by increase in value per unit of volume. A point to be noted is that during regeneration operations, when the seed trees are given more room and light, they may respond by increased increment. This extra growth laid down on selected good mature boles may carry with it a considerable increase in value. The same thing happens with the selected good trees retained to full age in uneven-aged forests. A simple instrument much used for providing information as to the current increment of growing trees is the *increment borer* (usually spoken of as a *Pressler's borer* after the inventor) which permits one to take a radial boring into the trunk for examination of the width of the annual rings of growth that have been laid down.

Sample Plots and Yield Tables. Estimates of the increment of whole crops under different treatments are ordinarily based on measurements taken in specially selected *sample plots* maintained for the purpose. Standardized techniques have been adopted for the

periodic (usually five-yearly) measurements of such sample plots, and it is essential for accuracy that precisely the same procedure shall be followed at each remeasurement. All the trees are numbered, marked at the standard breast-height point of measurement (in England, at 4 ft. 3 in. from the ground), and the girth or diameter (d.b.h.) is measured with a steel tape or accurate callipers. The other necessary measurements for height and volume are usually obtained from carefully selected *sample trees* felled for the purpose if possible, but otherwise measured standing in various ways. These data are necessary because the boles of trees vary appreciably in shape ('form'), but it is sometimes possible to use independently prepared *form factor* or *volume tables* for obtaining the volume of each sample tree, given one or two more easy measurements such as total height and d.b.h. The form factor expresses the relation of the actual volume of the bole to the volume of a cylinder of the same basal area and height. The volume table will give the average volume for trees of given height and b.h. diameter or girth. By the combination of data from sample plots of all ages and quality classes, the development and yields of a crop from start to finish can be calculated. Such data are sorted out for different qualities of site fertility (*site* or *quality class*) on the basis of the crop height attained at a given age such as fifty years, or on average height at maturity when height growth has practically ceased. The resultant tabular statements giving figures for ten (or five) year steps in age, by qualities, are termed '*yield tables*' and usually form the standard of reference in the preparation of the management plans to be discussed later. Hitherto it has only been possible to prepare such yield tables for even-aged crops of the

chief species. For irregular crops, studies are made in larger plots to determine the increment obtained on any given site class with different total standing volume and different proportions of the several size classes. From the data collected, it is possible to deduce the necessary conditions for maximum increment.

The techniques of measuring trees, tree crops and their increments constitute *Forest Mensuration.* In Britain, it is usual to measure girths rather than diameters so that tapes rather than callipers are generally used. Even in research work, the metric system is rarely used, and in practice girths and volumes are measured in what can only be described as a very old-fashioned method referred to as the *Quarter girth* method and the Hoppus foot of volume. The underlying idea was that if the volume for a log is obtained by squaring the quarter girth in inches at its mid-point (taped, estimated, or derived from quarter girth at breast height and special taper factors), dividing by 144 and multiplying by the length in feet, this volume may be taken as approximately that of the sawn timber which would be obtained on conversion. Actually this assumption involves a reduction from the cylindrical volume in the proportion of 4 to π, or 4 to $\frac{22}{7}$, or by $21\frac{1}{2}$ per cent. Care has always to be taken to note whether volumes have been measured over or under bark. If over bark, reduction for under bark volume may vary from 20 per cent. for larch, to under 10 per cent. for thin barked trees such as beech. Note is also required as to whether volumes are for convertible bole only, for all wood down to a specified minimum diameter of bole or of bole and branches, or actually total volume.

Various instruments are in use for the measurement

of the height of standing trees or the length of bole to any determinate point on the bole. With all of them, either a staff of known length is set at the base of the tree, or the distance from the tree to the point at which the instrument it used must be measured. Some of the instruments will then give a direct reading of height whilst others call for the use of tables permitting the conversion of the readings into actual height.

The use of Pressler's borer for the determination of increment has been mentioned. The borings for measurement of the annual rings of growth must be so taken as to allow for unequal growth along different radii. Growth studies are also possible on the stumps of felled trees by counting the annual rings and measuring radial distances for appropriate periods of years, or the number of rings in successive radial lengths, say of one inch. A standard procedure must be followed on all stumps examined and adjustments are necessary to convert stump measurements to those at the standard breast height. Very similar techniques can be applied to sections made at different heights on the bole of a felled tree which will permit of the reconstruction of the progress of growth in height and volume as well as girth. These procedures are briefly referred to as *stump analysis* and *stem analysis.*

In discussing sample plots, or volume increment plots, we noted that many of the data required are derived from measurement, not of all the trees in the plot, but only certain of them, the *sample trees.* Special precautions have to be taken in the selection of the sample trees and in the derivation of the crop data from their measurement to ensure accuracy. This problem of the selection of acceptable samples and the estimation of the precision of the estimates based on

them underlies nearly all this work, as also all methods of determining the volume of whole forests (cruising), but for details the special literature must be consulted. Of recent years, precisely the same principles have been applied to almost all aspects of experimental research work and the recognized necessity of the statistical analysis of growth data obtained with different treatments has reacted on the methods adopted in laying out the experiments.

Forest Management. Before a definite plan of management can be satisfactorily drawn up for any given forest area even after the silvicultural treatment is decided, there are certain matters of general policy and economics still to be taken into account. It is obvious that the forest manager must have clearly defined objects in view at all stages of his work. These objects must be not only silviculturally attainable but they should be in line with the policy laid down by the owner—or by the State where the State is in control—and they should be as sound and profitable economically as conditions permit. So one of the first steps is to set out the objects of management, involving decisions as to the purposes the forest is to serve, the kinds and dimensions of timber to be grown, the markets to be supplied and so on. It will be noted that whilst silviculture is mainly concerned with qualitative methods of treating tree crops, management has to pay full attention to the quantitative aspects of areas, volumes and time, to ensure regular supplies of produce and to equalize the demands on the labour force. The preparation of management plans, or forest *working plans* as they are usually termed, is rightly looked upon as one of the main responsibilities of those in professional charge of forests. Forestry is by its very nature a

long-term business, and it is of the greatest importance to conduct the work in accordance with a definite plan drawn up to conform to long-term objectives.

We will first consider large scale forestry to be practised in existing forests, as is typical of the State forests of Western Europe and India, and see subsequently what modifications are necessary under other circumstances. The chief matters to be covered by a working plan have been reviewed in the foregoing chapters and the problem now is their application in suitable form to a specific area. For a fully organized forest, we shall need to discuss in turn the following:

(1) Subdivision of the area for management purposes.
(2) The silvicultural systems to be applied to different parts.
(3) Rotation.
(4) Calculation of yields for the period of the plan.
(5) Felling prescriptions, etc.
(6) Other prescriptions for protection, communications, etc.
(7) Financial forecast.
(8) Method of check that the annual prescriptions are carried out.

The first task is a detailed examination of the contents of the forest and the conditions for growth. This will be done with an amount of detail commensurate with the nature and value of the forest and the intensity of management contemplated. Maps (called *stock maps*) showing much of this information will ordinarily be prepared. Next comes a survey of all the conditions affecting the working of the forest, e.g. rights to produce, etc., markets, labour supply, risk of injury by fire, insects, etc. Subdivision of the

area into relatively small units termed *compartments*, say 10 to 25 acres each, will be necessary for this if it has not already been done. These are the real management units. They should be bounded by natural or artificial boundaries such as rides, streams and ridges, and each should carry a permanent number. During the stock-mapping or subsequently, collection of any mensuration statistics needed, such as volume of growing stock, current increment, and the estimated yield per acre for each type of felling prescribed, will be carried out. All these matters form the background material for the actual prescriptions and are often referred to as Part I of the Working Plan, the prescriptions forming Part II.

The stage has now been reached when it is possible to draw up proposals for the work to be done in the forest to realize the permissible yields and to guide development in the desired directions. In order to meet a variety of objectives and to make the best of the frequently very varied conditions and potentialities of the forest, it may be desirable to divide it up into two or more parts called *Working Circles*, not necessarily a continuous area, each of which will be worked separately on the lines most suited to it and to the particular purposes it should serve. A working circle may itself be further divided into two or more *felling series*, all worked in the same way, but each forming a complete independent unit; this is often desirable to supply separate markets or industrial units.

The silvicultural system most suitable for each working circle is then decided, on the basis of the special objects it is to serve considered in conjunction with the condition of the crop. In each compartment it will have been noted what silvicultural operations

seemed called for with what degree of urgency, and the task now arises of making adjustments to even out irregularities, and so to guide development in each unit as to fit best with the general plan.

It is usually necessary to determine the age at which crops or trees shall be considered mature and ready for fellings—this age being termed the *rotation age*. Foresters distinguish several kinds of rotation according to the factor on which most stress is laid, e.g. there is the *financial rotation* which gives the highest financial return for the forest as a whole, or the *rotation of maximum volume*. Most usually, the figure chosen is a compromise between several considerations, but it must conform to the requirements for regeneration and for the available markets. Customary rotations are 150–200 years for oak, 100–120 for beech, 80–100 for Scots pine, and 60–80 for other conifers, 25–30 for poplars, and 15–20 for cricket-bat willow.

The basis of *yield regulation* is nearly always to aim at the maximum *sustained yield* from the forest, in order to regularize supplies to markets and industries, as well as to ensure regular employment of the labour force and machinery. An attempt has to be made to determine what is the maximum sustained yield that the forests in question are capable of giving, and so to handle the forest that the actual growing stock is gradually brought into the condition which would ensure the maintenance of this maximum yield in perpetuity. This ideal or *normal* forest would have all age classes of trees or crops represented in such proportions that every year the same amount of timber would be available from fellings of all kinds; it may be noted that the total amount of these fellings in the normal forest would equal the total annual growth of

the forest as a whole. It is possible for a forest to hold more than this *normal growing stock*, in which case it is permissible for the fellings temporarily to exceed the maximum sustained yield, whilst on the other hand, in an understocked forest, growing stock will have to be built up by reducing fellings as long as necessary.

Plan of Operations. Although the forest working plan takes into account the general lines to be followed over a long period, it ordinarily only goes into details for the relatively short period of ten or fifteen years. For this period, it will prescribe by compartments all the operations to be carried out in each year. Under the systems with concentrated regeneration, the area to be brought under regeneration during the period of the plan is usually examined in greater detail than the rest, as the bulk of the timber and monetary yield will ordinarily have to be obtained from it. As however the exact location and progress of the fellings will depend on the success attained in regeneration, it is not possible to give exact prescriptions, but only to outline the principles to which the operations must conform. For other compartments, cleanings, thinnings, improvement fellings, or any other necessary operations will be prescribed according to their several requirements and in sufficient detail to ensure the desired treatment. Under the selection system, the one felling operation will take trees of all sizes, and special care is needed to guide the crop in each compartment towards optimum growing stock and appropriate distribution of size classes; for this periodic full enumerations are necessary.

Besides the felling and regeneration operations, the working plan will also deal with other operations necessary to the efficient management of the forest. This may include construction and maintenance of

roads, buildings and boundaries, and any special measures to be taken for the protection of the forest against fire, insects, disease or any other hazards. It may also prescribe any special experimental work necessary to yield information needed for the future better management of the forest. There may also be special sections dealing with such matters as the provision for meeting requirements of right-holders, sporting requirements and any other matters involved in the management of the forest.

Financial Forecast. Forest management is of course a business affair and it is essential that full consideration shall be given to the cost of all operations prescribed, together with due allowances for overheads, maintenance and depreciation of equipment and all other incidental expenses, to be compared with estimates of the financial returns to be derived from the sale of produce and other sources. Obviously opening and closing balances must be struck which implies that in addition to the cash aspects, the value of the assets at the beginning and end of the work must be taken into account. The main asset is the value of the forest itself and the far from perfect condition of most forests calls for the reinvestment of a large proportion of the returns in the business. Where records are available for forests which have gradually been improved in this way, as in many parts of India, there has been a most striking increase in the capital value of the forest and, in due course, an equally marked increase in the sustained yields and the revenues they produce.

Control and Records. To ensure proper carrying out of the prescriptions of a working plan, it is necessary to provide for an annual check of work actually done against work prescribed, to see that arrears of work

are carried forward instead of being overlooked, that excess fellings from any cause are compensated by an equivalent reduction later, and generally to ensure that no significant change is made from the prescriptions of the plan without at least as much consideration as was given to the original drawing up of the plan. Wherever possible, as it is in most State forest departments, it is desirable for this control to be carried out by an independent authority, and standard forms are generally used for the purpose. It is also important that in addition to the summary given in these control forms, a more detailed record shall be kept of all operations carried out and events affecting the growing stock in each compartment. This is usually done in standard form in a *Compartment History* or *Compartment Register*. These records provide most important material for the revision of the plan at the end of the period for which it has been drawn up. In Britain, the function of control of operations in 'dedicated' privately owned forests is carried out by the Forestry Commission, and is a condition for the payment of grants.

Simpler Working Plans. It was pointed out at the commencement of the foregoing description of a working plan, that it is only generally applicable to large scale work with fairly intensive management. These conditions however often do not hold as on small properties, or recent afforestation projects, or extensive areas of forest of little present value, and brief consideration of the connected management problems is called for. The guiding principles must still be the same, viz. to reach a decision as to the ultimate long term objectives and to draw up a programme of work for a period of several years at least, in conformity

with those objectives. Such a programme is sometimes called a *Working Scheme* or a *Plan of Operations* (as under the Dedication Scheme for private woodlands in the U.K.) and may be a very simple affair, in the extreme case doing little more than prescribe the correct silvicultural treatment of the stands as they exist, without any attempt at sustained yield, normal age class structure, or even regeneration. This may be quite acceptable under the conditions in question provided it is arrived at after due consideration of objectives and practical possibilities. In the case of low value or at present undeveloped forests, the working or management plan might similarly amount to nothing more than organized protection and the meeting of petty demands in a way least harmful (or most beneficial) to the growing stock. Always, there should be clear objectives and systematic check that all is in order to ensure that the forest is properly protected, and that in whatever is done or is permitted in the forest, due regard is given to its effects on the future growth of the forest.

Economics. Forestry is a business as well as a science so that the economic aspects of the policy and the work done have to be kept continuously in mind. In the foregoing account we have briefly examined the basic questions of supply and demand, but we have said very little about price beyond noting that prices have to be kept as low as possible, both because wood is an essential material for the maintenance of a tolerable standard of living and because it is subject to competition by alternative materials for a great many purposes. Records are available for the fluctuations of timber prices for over a century. These showed a slight but steady fall from 1850 to the early nineties and then rose

somewhat until the First World War created completely abnormal conditions. Referred to the purchasing power of money, the drop came rather earlier and subsequently rose at an average rate of $\frac{3}{4}$ per cent. per annum.

Expenditure. The most important component of the cost and ultimately the price of wood is labour, particularly as affecting transport and processing, and the possibilities of keeping down sale prices depend mainly on the economies that can be made on this item. Unfortunately, forestry does not lend itself to the same high degree of mechanization as does agriculture, and is spread over large areas, but even so felling and extraction have already been very largely mechanized, as well as most processing operations. Nursery work can be mechanized to a certain extent particularly if centralized, but planting, weeding, and most tending operations seem likely to remain manual, so that economies must be sought more from improved efficiency in organization. There have been relatively few of the costing studies which should help in indicating where economies might be effected.

Income. This must mostly come from the sale of timber and so the forester aims at the maximum sustained yield of high quality timber. There may however be important contributions to be obtained from minor products such as resin or bark, and it may be profitable to raise and market extra nursery stock. Shooting rents may also bring in something and there are sidelines such as sale of Christmas trees and greenery. Experience has shown that full development of these secondary sources of income and efficient marketing may often provide the profit on forestry, the timber covering the expenditure.

Profitableness of Forestry. The value of a forest as a going concern is determined not merely by what the wood standing in it at the moment would fetch in the market. Obviously the young regeneration and small poles have little or no immediate value but a considerable potential value. To get a figure for real value, it is necessary to estimate all these potential values and discount them to present values. A decision has to be made as to what rate of interest to use for this calculation (known as the *forest per cent.*). It has been customary to take the rate at which money can be borrowed for forestry. For the money yields to be obtained, the volume yield tables described on p. 158 have to be converted into *money yield tables* from a knowledge of sale prices of trees of different sizes.

If the financial prospects of a plantation or a normal forest for which money yield tables are available are calculated in this way, with due allowance for costs of original establishment and maintenance, using an agreed rate of interest but different rotations, it will be found that the calculated return will rise to a maximum for a certain rotation and then fall. This maximum is reached earlier for higher rates of interest.

Calculations of this nature enable us to determine what rotation is most profitable under any given set of conditions, this being termed the *financial rotation.* There are several ways of looking at the problem for which the textbooks must be consulted, but it should be noted the rotation which would give the maximum net income would be considerably higher than that which would give the maximum per cent. return on the capital value of the forest.

There are very few cases where the full record is available to permit of calculating the actual profitable-

ness of plantations but there are two classic examples from India. The teak plantations at Nilambur in Madras have been shown to have yielded, over eighty years, 6·9 per cent. on the money invested in them. Similarly the irrigated plantations of Changa Manga in the Punjab have been estimated to have given 4·67 per cent.

The history of the forest revenues from the State forests of India shows that the introduction of systematic protection and working into unmanaged forests is a profitable measure from the national point of view. Since the formation of a Forest Service, the revenue has doubled roughly every fifteen years from about £278,000 in 1868 to £9,000,000 in 1944, or thirty-two-fold in seventy-six years.

Chapter XII

RECLAMATION AND AFFORESTATION

BESIDES the management of already existing forests, a great deal of the forester's time is taken up with the work of restoring as good a forest cover as possible to land which has been denuded of trees and to the afforestation of land which has never carried forest, at least not for a very long time. We have both problems in Britain, and the former is very extensively encountered in other countries, particularly in the underdeveloped countries where the population densities are so great that the original forest has been largely denuded or seriously degraded by long-continued excessive and unwise use. Even where the need for fuel and construction material can be met from more distant forests, it comes at last to be realized that the destruction of forest cover is liable to cause disastrous landslips and soil erosion, particularly on sloping ground. This has led to the undertaking of reclamation work which has largely fallen to the forester, though the task is really appropriate to a team of workers including agriculturists and grassland managers. It is usually true to say that an acre of land lost to food production leads to the loss of at least one more acre of forest from the dwindling reserves.

Shortages of Fuel and Timber. The most common reason for the initiation of reclamation works of this kind has been the exhaustion of local supplies of wood fuel, though where alternative building materials are not easily available, the need for these may become

equally acute. As long as there is any woody growth available to a village, the process of forest destruction will continue, until there is nothing left, not even the roots of shrubs. The day comes when these essentials of life must be stolen from neighbouring land if it too has not been similarly devastated, and ultimately the only course left is to rob the fields of agricultural waste as has already been mentioned, and standards of living inevitably fall. The suggestion that some of the village waste land be protected against grazing and fire and replanted may now be listened to, though there will inevitably be difficulty in deciding which particular plot of land shall be taken in hand.

A similar situation may arise with regard to the larger centres of population, but there is usually more cash available and the shortages may be made up by purchasing material derived from relatively distant forests. Efficient organization, particularly as regards transport, will often make it possible to keep selling prices within the reach of the people. However, the fuel and timber demands of many towns in the under-developed countries are now being met from areas expressly reclaimed and reforested for the purpose. The same problem arises in the case of local industrial requirements, such as those of mines and electrical power plants, and sometimes the same solution has been applied. Soil conservation through forest operations is being undertaken to an increasing extent as the disastrous results of denudation, such as landslips, flooding and loss of irrigation water supplies, have become more generally recognized.

Reclamation by Protection. It may often go a long way to remedy a thoroughly unsatisfactory situation merely to introduce effective protection regulations

against unauthorized cutting, burning, and grazing. Instances might be quoted from several parts of the world where such protection has resulted in the fairly rapid re-establishment of a soil cover to which woody plants, grass, and herbs all contribute, and in a great diminution of erosion, and ultimately in bringing the land back into production of useful forest material such as fodder, poles, and fuel. Instances could also unfortunately be quoted where such successful work has been completely undone again by a few years' withdrawal of the protection which has worked such a transformation. When the fertile top soil has been lost and such subsoil as is present is inadequate in depth and slow to develop into a new soil, reclamation work may progress very slowly indeed. There may be only pockets of often poor soil in which a few plants can be established scattered irregularly over the area. In the wet tropics, some of the most common types of soil harden on exposure to an extremely infertile brick-like material (laterite) on which hardly anything will grow despite quite favourable climatic conditions.

N.W. Europe. In Britain and parts of the other countries bordering the North Sea, we have to deal with a rather special case of the consequences of forest clearance. Erosion effects are rarely noticeable and the ground tends to be taken over by grass on the better soils and by dwarf shrubs, particularly of the heath family, on poorer sandy soils. In both grass and heath, the natural or artificial re-establishment of the original tree species, generally oak, beech and birch, is slow, or even almost impossible on the heathlands where even hardy conifers such as Scots pine may be effectively excluded by the fires which periodically sweep across them. In parts of such areas, swampy

conditions are also liable to set in or at least to be accentuated, and peat bogs may develop, effectively excluding the re-establishment of a tree cover. The methods of reclamation and afforestation of heathland, wet peat areas, and grassland in Britain will be described in a later chapter, so that it is only necessary to note here that the general approach to the problems involved has been to try to reverse the processes which have gone on in the soil since the original tree cover was removed, and so to restore the lost fertility. Loss of mineral nutrients and increased acidity are the chief causes of deterioration, so that measures such as addition of manures and lime suggest themselves. City refuse has been most effectively used to fertilize heathlands in Holland, and phosphatic manures have proved very useful. Large areas of heathland have been reclaimed in Germany, Holland, Belgium, and Denmark as well as in Britain, where the greater part of the annual afforestation programme of some 50,000 acres can only be provided from the heather-clad hill moorlands.

Southern Hemisphere. Returning to what has been and is being done in other countries, one is struck by the fact that South Africa, New Zealand, and South Australia have over recent years all built up very extensive plantations of exotic trees, the areas being approximately 1,520,000 acres, 880,000 acres, and 90,000 acres respectively. Some of the land in question was already carrying tree or scrub growth. The species predominantly used are pines, particularly Monterey pine (*P. radiata* or *P. insignis*) and *P. patula* for saw timber and pulpwood, eucalypts mainly for fuel, and one of the Australian wattles for tan bark. This great work has been undertaken to make up national shortages of timber or other produce, and also as a purely

financial investment, the returns coming from sale to local industries or from exports.

Shelterbelts. Very extensive tree planting has been done in certain parts of the world to give protection from wind and the soil erosion that it causes. Much of the land so planted is actually agricultural land, but the farmers have recognized that they stand to gain more from the protection and production provided by the planted tree belts than they lose by giving up a relatively small proportion of land for the purpose. The outstanding examples from the U.S.A. and Ukraine have already been mentioned. The raising and maintenance of shelterbelts is perhaps not quite so simple as it would at first appear to be. An obstruction through which the wind filters with loss in velocity is a much more efficient protection than a solid obstruction such as a wall. The profile of the belt also needs to be such as to deflect upwards the wind sweeping over the surface of the ground. To do this the species used are so chosen that the height attained by them increases gradually from that of a low shrub on the windward edge to the full height of the large trees planted in the middle of the belt. Such belts may be 400 to 500 yards apart. Even where there is a pronounced prevalent direction of the wind, it must be taken into account that dangerous winds may also sometimes come from other directions. The main belts are accordingly aligned across the prevalent wind but they are linked to the adjoining lines by occasional cross lines at about half-mile intervals.

Fixation of Sand Dunes. Consideration of shelterbelts leads to the pronounced protective effect that a tree cover can give to land threatened by wind erosion and advancing sand dunes. We have well-known cases

in Britain in the Culbin Sands and in East Anglia. Although sand dunes appear very dry, they do in fact usually contain a considerable amount of moisture below the surface and in the case of coastal dunes at least, and sometimes river bed dunes, the water table may not be very deep. The problem is one of finding a tree that will grow under these conditions, and methods of ensuring rapid root penetration to the water supply.

The classic example of dune fixation in the Landes already quoted was commenced in 1787 by one of Napoleon's engineers, Brémontier. The dune grasses, notably *marram*, were planted and many other materials, dead or living, were used for checking the movement of the sand. It was found possible to build up not far from the foreshore a fairly high littoral dune which, if properly maintained, gave sufficient protection to permit of the growth of the maritime pine a little further inland. The shape of the trees at the seaward edge and their rate of growth there were naturally very poor, but they gave sufficient protection to the leeward to permit of quite reasonable growth. As soon as cover was established in this way, the hitherto moving sand was stabilized apart from occasional setbacks, and the threat to the fields beyond was removed. It was also found that the swampy hollows between the dunes gradually dried out as the forest cover became established, and a former highly malarial region gradually developed into a salubrious resort. The progress of the work was further helped by the development of an important resin tapping and distilling industry, giving a lot of local employment, whilst the timber, even if only of relatively low quality, was suitable for use on a large scale for certain purposes such as pit props and

(after impregnation with a preservative) for telephone poles. The one big menace is still fire. The total length of this pine belt is some 150 miles, and the area of forest, about equally divided between State and private owners, amounts to something like a quarter of a million acres.

Inland Dunes. The problem of fixing the moving dunes extending from the larger desert areas and their fringes over the adjoining dry country is much more difficult, mainly because of their dryness and the great risk of depredations of goats and camels on any plants raised. Reference has already been made to the talk about the advance of the deserts in Africa, Western India, etc. with a tendency to find an explanation in a possible drop in rainfall caused by denudation of the natural vegetation. Reliable evidence is difficult to come by, but there can be no questioning the fact that grazing and temporary cultivation, if not the sole or even the main cause, are at least very important contributory factors. Here efficient protection of the danger zones must be the first step, providing a palliative while more active measures are being introduced to establish growth of some sort or another on the dunes themselves. Considerable shelterbelt projects are under discussion but very little has yet been done.

Swamps. The question is often asked whether, in view of the established fact that trees use a lot of water drawn from the soil, it is a practical proposition to drain swamps by afforesting them. Given certain conditions the answer is Yes. It is usually essential to open drains and build ridges or mounds to give the seedlings or plants a chance to become established, and it becomes difficult to determine how much of the subsequent drying is due to the drains and how much to the new

tree crop. However this may be, excellent plantations of eucalypts have been raised in *papyrus* swamps in Uganda, and the example quoted from the Landes may be borne in mind. In our own forests, the spruces certainly have some effect in the right direction. Many tropical swamp forests seem destined ultimately to become rice-growing land, as they already have so extensively in the East.

Arid Plains. In the drier tropical regions, particularly in India, the general pressure of population on the land has tended to restrict the area available for forest use to the poorest soils and sites, all the better ones being taken up for food production. The problems involved are to a very considerable extent determined by the availability or non-availability of water for the plantations. Where no water is available, the choice of species is very restricted, though there are possibilities of some improvement on the natural vegetation through the importation of suitable exotics. Thus the *mesquite* of America has proved very useful in some other parts of the world. The techniques adopted are based on those of dry farming, aiming at encouraging the maximum penetration by roots during the short growing season and the application of all possible measures for moisture conservation. This ordinarily involves a deep soil working particularly important in hard soils, and keeping the top surface free of competing weeds and well worked to form a protective mulch to the deeper layers. Timely sowings usually give better results than planting, but one must be prepared to repeat the sowing if breaks in the rainfall are likely to render it necessary. In extreme cases the whole work may fail in a year of low rainfall, but this does not necessarily mean that quite satisfactory results may not be obtained

by precisely the same procedure in the following year. Various kinds of *Acacia* are chiefly used in this work, particularly *A. arabica* which has an additional advantage in being more tolerant of saline soils than most other species. This matter of salinity is frequently encountered in hot dry tracts where there is a tendency for soil moisture with salts in solution to move upwards to replace the losses due to evaporation; this process leads to a concentration of salts in the surface layers which may inhibit practically all plant growth, particularly from seed. No remedy is known without the use of water.

Over recent years large areas of semi-desert country with from 15 to 5 inches of rainfall have been brought into production by irrigation from canal systems based on the large rivers. Approximately 20,000,000 acres of land have been so treated in the alluvial plain of the Indus and its tributaries, and considerable areas have been earmarked for afforestation to meet the needs of the agricultural colonists. The aggregate area of such plantations is about 100,000 acres. The water is usually distributed over the area to be planted by a system of minor canals and finally trenches about 10 ft. apart. Sometimes sowings are made along the edge of the trenches but the planting of stumps is now very general as the main species used (*Dalbergia sissoo*) takes well if planted this way. The trenches have to be refilled every few weeks, not only during the first year but continuously thereafter. The amount of irrigation water likely to be required is the equivalent of about 50 inches of rainfall; sometimes the ground is flooded instead of being irrigated from trenches. In this way remarkable results have been obtained and the plantations have not only produced a supply of essential fuel and

timber but have been financially profitable notwithstanding the considerable sum paid for the water. Besides blocks of plantations, hundreds of miles of canal-side strips have been planted up in India and Pakistan.

Denuded Hillsides. In many parts of the world the problem has arisen of reclothing denuded hillsides with woody vegetation to reduce soil erosion, to stabilize landslips and reduce the likelihood of their recurrence, and to reconstitute a mantle of soil capable of storing water for the maintenance of springs. The special problems encountered are the usually excessively free drainage, difficulties of establishing trees on hot dry sites particularly on southerly and westerly aspects, and in many cases instability of the soil of screes, etc. making rooting difficult. Many such sites however enjoy reasonably favourable climatic conditions during the moister parts of the year. Where the soil is unstable the first problem is to fix it. This is done by a combination of planting and mechanical work, cuttings of trees such as alders and poplars combining both methods being particularly successful. Often it is a question, at least at first, not of attempting to introduce straight away a valuable species, but anything that will grow—grass, weeds or climbers. Again in many places simple soil conservation measures such as 'gully plugging' and digging contour trenches have to be undertaken to slow down the surface run-off of water and to collect soil in which to establish new growth. Extensive work of this kind has long been in progress in Japan and in Italy, where a common practice is a method of breaking the slope into steps termed 'gradoni' which are then sown or planted. This method has been considerably extended to other Mediterranean countries, for example

Cyprus, which has recently become a demonstration ground for the Middle East. Gully plugging involves the construction of small dams of any available material in the minor water courses so that the hollows behind the dams will silt up and can then be planted up.

Ravine Land. A special case of reclamation of sloping ground is presented by the ravine country developed through accelerated erosion in uncompacted soils. Large areas of this type are met with in several parts of the world, mainly in old alluvial or blown soils, e.g. the loess of China, through which the main water courses have excavated deep beds. If such soils are deprived of protective vegetation, the run-off is liable to cut deep gullies and ravines each of which will continuously head back into the higher land. Remedial measures are to divert as much as possible of the water which would otherwise reach the head of each ravine, to reduce the gradients wherever excessive, and to plant up in the first place with anything that will grow, covering and stabilizing the soil, after which permanent species suitable to the locality may be introduced. Frequently exclusion of livestock will result in the development of a protective cover of grass and herbage.

Chapter XIII

FOREST POLICY AND LAW: RESEARCH AND EDUCATION

It has already been stressed that forestry is a long term business so that it is particularly important to be clear what the objectives are before starting work. If this is true for the management of an individual forest, it is doubly so when considering forestry from the national point of view. We must be decided what purposes we expect the forests to fulfil, what produce we require from them, how large an area of forest is essential to fulfil the national needs, how it should be distributed, and how large an area would be desirable if available.

In considering these matters, we have to take into account not merely the needs of the moment but those of at least a human generation or two ahead. Admittedly various estimates for which the basic data are very scanty have to be made, but it is far preferable and simpler to revise well-based objectives and programmes from time to time as conditions change, than to adopt any procedure involving drift as opposed to guided development. The special position in this country will be discussed in the following chapter, but in the world picture it is perhaps correct to say that the protective function of the forests must be considered before the production aspect, important to us as timber supplies are. The maintenance of a considerable area of forest is frequently essential in the general interest for the conservation of soil and water supplies and for protection of land, crops and habitations against wind.

This may be the case quite independently of the value of the produce such forest will at the same time certainly be able to yield. As we have already seen, once the forest cover is fully established, we shall be able—and indeed entitled—to harvest every year an amount equal to the annual growth of the forest as a whole.

When we were considering the consumption of timber and fuel associated with an acceptable standard of living, we saw that it is possible to arrive at an approximate figure for the total area of forest a country needs to meet its total requirements of wood. The demand may of course be more or less than the theoretical production of the forest areas needed for protective purposes. If it is more, then the difference must be made up by additional forest reservation or afforestation, or the choice will lie between lowering of levels of consumption and importing from outside. Owing to the unsettled international conditions that have continued so long, most countries now aim at producing at home as large a proportion of their domestic requirements as possible. Even after meeting the essential requirements of the population, it will ordinarily be very highly advantageous to a country to have additional productive forest providing the raw material for the wide range of industries which we have already reviewed, or at least material for export. There appears to be little likelihood of any highly developed tract of country having more timber than it can use or dispose of, such surpluses as exist being in the less developed and less accessible parts of the world. There are indeed those who think that wood is likely to become increasingly important as a raw material for chemical industry in future years. There are quite a

few countries where the export of surplus timber, often more or less processed, makes quite an important contribution to the national revenue, usefully providing payment for essential imports. British Honduras may be quoted as an extreme case, for its exports of forest produce have never fallen below 75 per cent. of the total value of exports since logwood and later mahogany began to be exported over a century ago.

Although the present proportion of the total land surface now covered by forest is the outcome of a variety of factors mostly independent of deliberate planning, they are interesting, and reference may be made to the table given in Chapter I (p. 6).

It is frequently stated that an appropriate figure to be aimed at is 20 to 25 per cent. of the total land surface, on the ground that this figure is approximately what is found in countries with a fairly well balanced economy in this matter, viz. France, Germany and Switzerland. However, conditions, climatic, geographic and economic, vary so enormously in different countries that any such figure may be very misleading in either direction. For example, in one country the area needed for protective purposes alone may well exceed this proportion; in another country more favourably situated, there may be relatively little forest that is essential for protective purposes, and at the same time a high production per acre may keep down the area needed for production. The problem must be dealt with independently in each country in the light of the local values for the many factors involved.

Not only the total area of forest but also its geographical distribution is important. Where other sources of fuel are not available, particularly in rural areas, it is important that there shall be adequate areas

of forest so distributed over the country that supplies may be reasonably accessible in all parts of it. A good system of communications may do something to alleviate the consequences of poor distribution, but the cost will inevitably be higher. It is very common to find that even where the total forest area is adequate or more than adequate, it is concentrated in a few special tracts, often in the hills and mountains far from the main centres of consumption. It therefore frequently becomes necessary to raise strategically distributed plantations, as was mentioned to be the practice in the irrigation areas of the Indus valley.

In determining what specific areas of land shall be allocated to forest use where land planning is still possible, it is necessary that the claims of forestry shall be considered at the same time as all other claims for agriculture, mineral development, etc. It is not sound to deal with forestry requirements independently, for difficulties very commonly arise when this is done. In the world of today, the provision of land for food production inevitably has the highest priority after the usually over-riding requirements for residence, industry and sometimes mining. As a rule, permanent forest use tends to be restricted to land which is less suitable for the other purposes, to the poorer soils, to the steeper slopes of hills and mountains, and to rocky ground. In all these sites, the land can often give a higher production under forest than under possible alternative or competing uses, whilst the position is frequently the reverse on the more productive soils. Among the reasons for this situation is that the forest use typically involves relatively little investment of capital or labour; the forest grows if only permitted to do so.

Mention must be made of the constantly recurring

problem of the competing claims for land for grazing where the only land available for forestry is at present used as rough grazing, and is in fact producing a certain amount of food as meat, milk, etc. as well as wool and hides. Any extension of forests inevitably means some displacement of stock and reduction in food production. Although it is generally indisputable that the unimproved land will be more productive under trees, it has to be admitted that if the same expenditure as is incurred in afforestation were directed to the improvement of the land as pasture, a considerable increase in carrying capacity and meat production would result. The chief point still at issue seems to be the duration of the benefits obtainable from pasture amelioration by the known techniques, mainly soil cultivation, manuring and re-seeding. It can however always be argued on the side of forestry, that if such improvement works were undertaken on rough pastures other than those taken up for forestry, the increased production which it is claimed would result could easily compensate for the loss of production due to the extension of the forests. In Britain, for example, afforestation is only contemplated for about two million acres out of the sixteen million acres of such land.

Multiple Use. It must not be thought that the land under forest serves no other purposes than the two major ones of protection and production so frequently mentioned, even if we include a measure of forest grazing among the productive aspects. Many woods and forests have a sporting value that is sometimes quite considerable, and they are extensively used for recreational purposes. This latter value is coming more and more to be recognized, and instances can be quoted, for example from the U.S.A., where over large

areas of nationally owned forest it has been given priority over all other uses. Most countries are not in the position to go to this extreme and find it quite possible to combine normal productive use with the recreational use, subject only to a few minor limitations, as in the case of the national forest parks of this country.

A further instance of this type of use is provided by the numerous forest game and wild life sanctuaries that have been proclaimed in various countries. Here the forest serves for the conservation of wild fauna and flora by direct protection and by maintaining the general conditions of the habitats essential to their survival. In this case there is still some difference of opinion as to what is the best course to adopt. Conservation enthusiasts are inclined to wish to ban all normal forestry activities, whereas this step if adopted may easily result in the gradual loss of just those habitat conditions which it was wished to maintain. As with the parks, the ideal is undoubtedly productive forest use subject to such limitations as are agreed to be advisable in the interests of the other use.

Ownership of Forest. In any discussion of a national policy for forestry, the question of ownership inevitably arises. Examples of the present position as regards the main types of ownership are given in the following table, also taken from data collected by U.N.F.A.O.

It will be seen that the full range occurs between predominantly private ownership to almost exclusively State ownership, but there is today a very general tendency towards increased public ownership in one form or another. The reasons for this are not difficult to find; they lie mainly in a dual development in the public attitude towards forests, namely the increasing recognition of the importance of forests to the common

welfare, and of the nature of forestry as a big scale long term activity more appropriately controlled by the State than by private owners with their almost inevitably short term views.

OWNERSHIP OF FORESTS

	Total Productive Forest. Thousand acres.	State owned. Per cent.	Communal and Institutional. Per cent.	Privately owned. Per cent.
U.K.	3,146	16·3	*	83·7
France	27,067	14·5	22·3	63·2
Germany	18,648	45·2	26·7	28·1
Switzerland	1,977	6·2	66·9	26·9
Netherlands	618	15·2	20·0	64·8
Finland	51,150	34·3	1·5	64·2
S. Africa	2,036	31·2	2·2	66·6
Kenya	1,364	85·0	12·7	2·3
Gold Coast	22,340	0·2	99·8	0·0
N. Borneo	12,160	33·2	66·3	0·5
Australia	50,045	69·1	1·2	29·7
New Zealand	4,870	77·0	2·6	20·4
Canada	520,383	87·3	0·4	12·3
U.S.A.	474,007	23·6	3·6	72·8
British Guiana	34,559	98·1	0·9	1·0

* Not separately recorded but very small.

State Control. There is however a possible alternative to State ownership which has a particular appeal in democratic countries. This alternative is that instead of acquiring the ownership of the forests, the State should limit its interference with private ownership to what is essential for the general welfare. It must however be prepared to take over the management of the private forest if the owner is not willing or able to undertake the operations considered necessary in the

public interest. There are many ways in which the State can encourage and help the private forest owner to carry out the necessary operations when they will not bring him in any return on his outlay, and the same applies to the afforestation of bare land. Such help may take the form of a grant or subsidy, of concessions in taxation, of technical aid and advice, and so on. This topic will be further dealt with in the account of forestry in Britain in the next chapter.

Co-operation. There are serious obstacles to the efficient management of small forest properties, the chief of which is the difficulty in marketing and in providing competent technical supervision. With the common modern tendency to the reduction and fragmentation of estates, this difficulty is increasing, but there are fairly satisfactory ways of getting over it which in most countries have not yet been fully applied. The most effective is co-operation between owners. This commonly starts with the marketing of produce, but can extend to cover the whole range of forestry activities. This co-operation may be organized among a group of adjoining properties or, at the opposite extreme, may be nation-wide and effected through a society big enough to maintain its own technical staff and even training centres: such societies have played a very important part in the forest history of the Netherlands and Scandinavian countries providing an agency through which the State can promote the attainment of the objectives of the national forest policy, with a minimum of bureaucratic interference.

It should be recognized that the present generation holds the forests as a trust for future generations. We are entitled to use the produce of our forests, national or private, so long as we maintain them in good productive

condition. Under emergency conditions such as prevail in wartime we may even draw heavily on them, provided we take immediate steps to restore them to a satisfactory condition at the end of the emergency. Once again, forests form a natural resource capable under proper management of self renewal, and it is our duty as trustees to maintain them in that condition. This attitude is of course recognized in our laws of entail.

Forest Law. As soon as the importance of forestry comes to be recognized and a national policy begins to crystallize out, legal enactments must be framed and passed to make it possible to implement it. Even before this stage is reached there will usually be many other laws applicable to trees and forest areas or produce, possibly exclusively applicable to them. Unless explicitly annulled or over-ridden by a later Forest Act, they will continue to apply. Many countries however now have a codified Forest Act which covers the majority of matters affecting forests. Different sections of such an Act will typically deal with different defined categories of forest such as State Forest, Protection Forest, Village (communal) Forest, and so on, and lay down a procedure for giving a specified area the appropriate legal status; there will be sections for the protection of the forest forbidding certain acts in the forests, and perhaps others prescribing acts that must be done in them. These latter sections imply the possibility of the commission of forest offences, so that procedure for enquiry and penalties have to be laid down. There is usually a section dealing with State control over private forests, and there may be others concerned with such matters as control over timber in transit by land or water. It is unnecessary here to go

into any greater detail but a few further particulars for the U.K. will be given in the next chapter.

Research. The solution of many current problems and the development of new improved techniques of forestry call for continued research work. Once again we encounter the special difficulties inherent in the relatively slow growth of trees and forests, and the large size of the plants and areas concerned. In the past, advances have been made through the experience of practitioners and the experiments carried out by them, particularly by those who have remained for long periods of twenty to forty years as the owners or managers of the same forests. Such methods, valuable as they still are, are no longer adequate to meet current demands, and more intensive research with modern instruments and methods is called for. This tends to be beyond the equipment and capacity of the practitioner, and has inevitably passed to special research institutions usually financed by the State, possessing the instruments and facilities, and staff with the necessary special background of scientific knowledge. Most of the work must, however, still be carried out in the forests themselves, and it is only special problems, particularly those involving detailed study of the way trees grow and how they react on the soil, that have to be brought into the laboratory. Many such studies come under the heading of ecology and their prosecution is very essential to provide the knowledge to enable the practitioner to make a wise choice of species to be planted or encouraged to maintain the fertility of a site; they may also provide him with suggestions for possible improvements in his practical techniques.

Forest Education. For the same reasons as apply to the prosecution of research, it ordinarily falls to the

State to provide most of the facilities for training men in forestry. At the professional level, many universities do provide courses in forestry, but most of them are helped if not entirely financed directly or indirectly by the State, whilst the majority of the openings for employment are in State service. Sub-professional training is almost universally provided by State forest departments as a normal part of their organization, though courses are occasionally run by professional organizations.

There remains for consideration a very important aspect of forest education, and that is the education of the general public to a recognition of the importance of a well-based national forest policy and the part they themselves should play in carrying it out. There are still very few countries which do not need a great deal of publicity work to be carried out by all the means available to the modern world. This applies to urban populations generally but also to rural areas, where the view tends to prevail that the forests always were there and always will be, to be used by everyone as he likes, whether they happen to be State, private, or communal property. Of recent years we have seen increasing organization of 'arbor days' and the like, the object of which is to lead an increasing proportion of the general public to think of trees from a more constructive point of view, with special stress on the need for planting trees to make up to some small extent the widespread clearances of the past. At present the greater part of such work produces little direct result since it is much more difficult to get the public to care for trees than to take a passing interest in planting them. All too frequently the planting has been done on unsuitable sites or with unsuitable kinds of trees, and

more often than not the planting has amounted to putting an odd tree here and a group of trees there, rather than a planned and concerted effort to create a wood where one was needed. There are however a few honourable exceptions and the whole movement has a definite publicity value which could in time lead to something really useful.

Chapter XIV

FORESTRY IN THE UNITED KINGDOM

History. In certain respects forestry has been practised in Britain for several centuries, but though constructive forest operations were being carried out from time to time on the Crown lands and larger private estates, there was no national forest organization until the Forestry Commission was set up towards the end of the First World War. Since then there has been considerable expansion in many directions and there is now a well organized professional Forest Service which compares well with the much older services of continental countries. It must however be remembered that in the closely linked field of arboriculture, this country has taken a leading part both in the early days and particularly during the Victorian period when explorers and seed collectors were being sent all over the world to find new trees and other plants for introduction to the gardens, parks and woods of the landowners of the country. Whilst the maximum stress was admittedly on the park and garden, not a few landowners, particularly in the north, were always on the look-out for suitable trees for use on a larger scale for timber production. In this way, Douglas fir and other exotics were raised in woods at early dates.

A feature of importance in the history of British forestry has been the continuous existence, in many cases since Norman times, of Crown forests distributed throughout the country and maintained and managed

primarily for hunting. Not a few of these forests have over the years been cleared or broken up, whilst others have been given away or sold. But some at least remain, even if reduced in extent, and have become State forests by a 1923 Act. The New Forest and the Forest of Dean are the most notable examples, but Delamere (Chester), Alice Holt (Hants) and Inverliever (Argyll) may also be mentioned. Naturally enough, when shortages of timber were experienced for public work such as the construction of ships for the Royal Navy, heavy demands have fallen on these Crown forests. This happened at the time of the Spanish Armada and the following period when John Evelyn was campaigning for forest planting, and again during and after the Napoleonic wars, very heavy fellings of oak timber were made, and in due course quite extensive replanting was undertaken. Around the 'Speech House' in the centre of the Forest of Dean, we can still see remnants of the replanting of ca. 1680, whilst there are still extensive plantations there and elsewhere dating from the post-Napoleonic replanting. In the course of time, various rights over the Crown forests became established by people living in and around them. The precise terms and exercise of these rights has been a repeated cause of dispute and has led to legislation attempting to regularize and stabilize the situation; thus the New Forest is governed by special Acts of 1877 and 1950.

The Acland Report 1918. Despite the recurrence of timber shortages, very little national action was taken to remedy the situation until 1885 when a parliamentary Select Committee was set up to report on the situation and make recommendations. Again little happened although a Development Commission was set up with limited powers and funds in 1909. In 1916 another

Forestry Committee presided over by Sir Francis Acland was given a similar task. Their report brought out clearly how desirable and indeed necessary it was that action should be taken by the State to increase the productive forest area of the country by making new plantations and improving the condition and production of the existing woodlands, which were mainly in private hands. The report recommended the setting up of a Forestry Authority to carry out the necessary work and in due course the Forestry Act of 1919 was passed. A Forestry Commission was set up, responsible not to a Minister but directly to Parliament itself, one of its number being a member of the Commons. The need for a professionally qualified staff was made clear. This report was accepted and a Commission of eight members under the chairmanship of Lord Lovat was formed in 1919 from which date State forestry may be said to have started in Britain.

The Forestry Fund. Under the Forestry Act 1919, £3½ million were provided for the Forestry Commission to carry out its assigned programme for the first decade. Plans and work were upset by the financial and other difficulties of the period, but over the decade grants actually totalled £4 million. During the second decade, there were again complications but somewhat over £6 million were actually received. It may be noted that under the Transfer of Woods Act 1923, the New Forest, the Forest of Dean, and some smaller Crown forests were transferred to the Commission and revenues from them were also available to meet part of the total expenditure. Receipts from all sources were running over £200,000 annually towards the end of the period and it is of interest to note that with the development of the new forests, helped admittedly by increase

of prices, the income in 1950–51 was almost exactly £2 million or ten times the previous figure. The net expenditure of the Forestry Commission over the period 1920 to 1951 has been roughly £80 million and the annual figure is now running at £6 million—a very considerable investment.

It should not be forgotten that although Britain appears to have been oblivious or at least negligent with regard to forestry at home, action was taken much earlier in respect of the important forests of the Indian Empire where the Forest Service was initiated in 1863. The establishment of forest schools for training officers for service in India provided part of the necessary machinery for launching similar work later on for the Colonies, and finally action was taken at home.

The Acland Report set out a programme of afforestation work calling for the planting up of some 20,000 acres annually, of which three-quarters were to be undertaken by the State. Twenty years later it was possible to report that out of the target of 745,000 acres of plantations to be created by the State in that time, 369,000 acres had actually been afforested or replanted. In order to encourage private owners, grants were also paid for new plantations, and in the same period these grants were collected in respect of an additional 125,862 acres, to which may be added some further area of new plantations for which the grants were not claimed. These latter figures were much less than had been hoped, and it was clear that neither the grants nor the facilities for loans that were also offered had provided the necessary stimulus to activity on a large scale.

Second World War. The position as regards timber supply became very serious indeed during the Second

World War when imports were almost entirely cut off for a considerable period. Few realized that we were importing roughly 95 per cent. of all the timber we used. To meet vital needs it became necessary to fell for immediate use practically all the suitable standing timber in the country that could be dealt with by the labour force and machinery available. The result was the felling, almost always clear felling, of about 1,500 million cubic feet of timber, over one-third of all the timber standing in the country, and a much higher proportion of the softwood. These proportions may be compared with about one-sixth or one-twelfth respectively that might be taken in normal fellings in properly managed forest over a six year period. It therefore became a matter of national importance both to make up for this enforced devastation and to adopt measures calculated to minimize the risks of again finding ourselves desperately short of an absolutely essential material.

'Robinson' Report 1945. The whole position was reviewed towards the end of the war and in the immediate post-war period on the basis of a report prepared for Parliament by the Forestry Commission with Lord Robinson as chairman. After some relatively minor amendments, the recommendations were accepted in the Forestry Act 1945, with a new programme of work for a fifty year period. At the end of this time, the area of productive woodland should have been brought up from two million to five million acres or from 5 per cent. to 9 per cent. of the total land surface. On completion of this programme we should be able to meet roughly one-third of our current needs from current yields, and hold a stock which should carry us over an emergency lasting several years without imports.

The greater part of the work is to be done by the

State, and in the first decade it will involve the acquisition of sufficient land to provide 500,000 acres suitable for new planting in addition to the replanting of 400,000 acres. More effective steps are also called for to ensure that private owners also make a considerable contribution both by replanting some 200,000 acres in the decade and by improvement of the remaining established woodland. The principle of grants for new plantations continues, but further inducement is given in the form of a maintenance grant per acre of productive forest; loan facilities are again available. An important feature with regard to privately owned woods is that these payments will ordinarily only be made provided the owners 'dedicate' the woods in question permanently to timber production and manage them under an approved working plan with qualified supervision. All the proposals were the subject of considerable discussion, but after certain adjustments, by 1951 general agreement had been reached and the dedication scheme well launched. Special arrangements apply to woods considered too small or otherwise unsuitable for the dedication machinery. The planting of poplars whether in blocks or lines also qualifies for a grant.

The Forestry Commission. It was also decided in 1945 that the old arrangement whereby the Commission had its own spokesman in Parliament was no longer acceptable, and that responsibility should be taken over by a Minister of His Majesty's Government. In view of the sometimes conflicting claims on land for forests and for agriculture it seemed appropriate that the Minister for Agriculture should assume charge in England, and the Secretary of State for Scotland in that country.

The Commission itself now consists of the Chairman and nine Commissioners, of whom at least one must have a scientific and technical knowledge of forestry, one (a 1951 addition), special knowledge and experience of the timber trade, and three, special knowledge and experience of forestry. The others are selected to give a wide range of forestry interests in all parts of Britain. There are National Advisory Committees for England, Scotland and Wales respectively, and eleven Regional Advisory Committees which have been set up, five in England, four in Scotland and two in Wales, to provide opportunities for the consideration of special regional problems and matters concerning the local application of national programmes, etc. There is also a statutory Home Grown Timber Advisory Committee appointed for consultation with representatives of organizations of woodland owners and the timber trade. The technical service had in 1951 a cadre of nearly 300 officers and 700 trained subordinate staff. Besides the Director-General and his Deputy, there are four Directors for England, Scotland, Wales, and Research and Education, and a Chief Engineer. Next come Divisional and District officers with territorial charges. Each district is divided into a small number of charges, each with a forester in charge. The engineering staff is distributed in a generally similar way.

Forestry Research. Research work is based on the Research Station founded in 1946 at Alice Holt in Hampshire, with branches for silviculture, ecology, mensuration (including census and sample plot work), pathology, entomology, and forest genetics. A great deal of the work is done in the forests all over the country, the northern parts being supervised from a subsidiary headquarters in Edinburgh. Machinery

research is also in progress, and research into Utilization Development has recently been initiated. Other research work is undertaken on behalf of the Forestry Commission at several universities and other institutions. A Research Advisory Committee of scientific experts in the various fields concerned is convened annually to review research programmes and reports. Research work on timber is arranged with the Forest Products Research Laboratory at Princes Risborough, Buckinghamshire, under the Department of Scientific and Industrial Research.

Forestry Problems. The dominant feature of forestry in Britain today is the big scale afforestation of non-forest land, mainly upland heather-clad moors. Second only to this, is the reclamation of the large areas of more or less derelict woodland, the legacy of two world wars. These two main tasks present a number of special problems which call for general review though they cannot be discussed in detail. Rapidly increasing in importance as the new plantations grow up is the utilization of the big volume of thinnings which is naturally predominantly in the form of small material: in 1951, 33,000 acres were thinned, 15,000 of them for the first time, in the State forests alone, and the total amount of produce from the State forests was eleven million cubic feet, about three million being pitwood.

Afforestation of Heathland, etc. We have already noted how much of our heathland has come into existence following the gradual disappearance of earlier forests. This process has been going on extensively at least since Bronze Age times, the last wave of exploitation clearing much of the Caledonian Forest for the industrial development in the southern parts of the country. It is now often difficult to state confidently

what were the original limits and nature of the forest. This is particularly so on the upland moors where there is the additional contributory factor of exposure to strong wind, which may moreover be salt-laden even at a considerable distance from the coast. It so happens that this heathy vegetation builds up a layer of very acid raw humus which is liable to react unfavourably on the soil beneath. For example, not far below the surface an iron pan may be developed through which roots can rarely penetrate and which moreover causes water-logged conditions during wet weather and excessive drying out during rainless spells. Efficient protection against fire and grazing may sometimes permit the development of the forest; thus Scots pine would rapidly reclothe many heathlands if given a chance, particularly in the south of England. Under the pine, the original hardwoods would probably gradually come in, as is very well illustrated in parts of the pine plantations which have been established on the Breckland of East Anglia.

Where the original forest conditions have been so fundamentally altered, sowing and planting methods suitable for normal conditions are often quite inadequate, and more drastic and expensive methods have usually to be adopted for afforesting the bare land. Over the last twenty years techniques have developed considerably, and they are still advancing. Heavy deep-going tractor drawn ploughs are now used to break through the iron pan, or any unduly compacted layers below the surface, and it is usually necessary for at least some mineral soil to be thrown up. This ploughing also very considerably alters the drainage of the site and the aeration of the soil in ways favourable to tree establishment. By far the greater part of the

planting must be done with conifers as they are so much hardier and more tolerant of poor acid soils than are the hardwoods. It is also true that with a few exceptions such as rowan and birch, conifers tend to extend much higher on the hills than hardwoods. Owing primarily to reasons of geological history, the only useful conifer native to Britain is the Scots pine, and were not other species available the work could not have extended as it has. A tree which was formerly a native until it was lost during the Ice Age is the Norway spruce and it grows well over a fairly wide range of sites, though rather sensitive to damage by the late spring frosts which characterize our insular climate. A very great impetus has been given to this class of work by the introduction of several other conifers from the west coast of North America where climatic conditions are rather similar to those experienced in Britain. The most important of these is the Sitka spruce, but we also use Lodgepole pine, Douglas fir, Western red cedar, Western hemlock, and a number of others on a smaller scale. It may be of interest to note that in 1951 the two spruces formed 42 per cent. of the total number of plants set out in Britain, the pines 26 per cent., larches 14 per cent., and broad-leaved trees 11 per cent. At Bedgebury in Kent, many exotics are under trial on the small plantation scale.

Afforestation of Chalkland. Another type of largely treeless ground for which afforestation comes into consideration is the open downland of the chalk ranges. Almost the only factors that are in common with the heathland are wind exposure and fire risks, for the soil tends to be too alkaline and there is trouble with a competing growth of grass. Experience has shown that

it is very often necessary to provide some sort of protection against the wind before a tree such as beech can be established. This protection may be obtained by planting conifers before or among the beech. Although these conifers will not grow to maturity, they do survive long enough to give the protection required and an early yield of saleable material as they are gradually removed. Resistant hardwoods such as alders and even hawthorn have also been tried, and shrubs such as broom and gorse, but usually only with moderate success.

Other Types of Land. Occasionally it is decided to plant up marginal or even small areas of reasonably good agricultural land, usually with oak and other hardwoods. Conditions naturally tend to be more favourable and good results may be obtained; the soil preparation work will of course usually be mechanized. There are considerable areas of rather poor sandy land in some parts of the country, the outstanding example being the Breckland of East Anglia, mainly blown sand overlying chalk. This area constitutes one of the Forestry Commission's most successful undertakings, 33,470 acres having been brought under plantation, mostly with pines.

Hardwood Forests. The 1950 Census showed that we still have 230,000 acres of coppice with standards and 120,000 acres of simple coppice, and we have seen that these forms of management are nowadays rarely paying. Conversion to more productive high forest can be brought about in a variety of ways which have been under close study for nearly a century on the Continent. It is usually a question of working towards a fairly complete high canopy by increasing the number of standards, supplementing them by storing the best

coppice shoots, and then regenerating naturally or artificially under a shelterwood or with clear felling. Natural regeneration of oak and beech has proved difficult in Britain, some part of the difficulty coming from the infrequence of good seed years and the number of vermin, both birds and rodents, that the forester has to contend with—in the State forests, 235,000 hares and rabbits, and 20,000 grey squirrels were destroyed in 1951. Nevertheless there are fairly large areas of concentrated oak regeneration in the Forest of Dean and of beech locally in the Chilterns, and some mixed woods carry a lot of seedlings, e.g. Lord Bathurst's Estate at Cirencester.

Derelict Woodlands. Coming now to the reclamation of existing inferior woodlands, particularly hardwood areas, it must be admitted that quite apart from 660,000 acres of war fellings, not yet replanted, much of this woodland is in very poor condition owing to past lack of proper management for timber production. The recent Census shows that, the assertion made many years ago by one of our foremost foresters is still true, that many of our hardwood forests, which are mostly in private ownership, are not producing more than a small proportion (about one-third) of the quantity of wood that they are capable of producing, whilst such growth as takes place is largely in the form of fuel or inferior logs. We are faced with the necessity of a reclamation programme affecting 150,000 acres of such low grade forest, much of it natural regrowth of inferior species which has sprung up since wartime fellings. Although the site conditions are usually much more favourable than on the new afforestation areas, the work is very difficult and expensive and the return from hardwoods in the early years of their growth is low

and delayed. Ash is somewhat of an exception in this respect but is very choosy as to site, relatively little ground being really suitable for it, and that mostly only in relatively small patches. Regeneration of acceptable species is generally very deficient so that at least supplementation by planting seems called for, if not complete replanting. The main difficulty arises from the strong regrowth of the scrub (particularly hazel and birch) cut back to make room for the new stock. This operation has to be repeated many times and becomes very costly, whilst the expense of netting against rabbits is also almost always unavoidable. Various methods of overcoming these difficulties are under experiment. Quick-growing conifers such as Douglas fir and hemlock offer best prospects for planting. It may however be found most effective to help the best of the regrowth of whatever species to develop as soon as possible into a new crop which will shade out the coppice scrub and render underplanting with a good species a practical proposition. Another plan is to introduce groups of timber trees through the coppice which is gradually cut back as the groups develop.

Control of Fellings. We have already seen that the standing timber volume forming both the national reserve against new emergencies and the growing stock which is required to continue producing timber has been extremely seriously depleted by the demands of two wars and reconstruction periods. It is obviously essential to restrict further fellings to what should be removed in thinnings and in trees deteriorating or about to deteriorate, subject only to the consideration that enough timber should if possible be made available to the home timber industry to keep it alive and capable

of expansion as our permissible cut increases with the natural growth of the new plantations. Under the Forestry Act 1951, with minor exceptions, timber fellings may only be made under licence from the Forestry Commission, *and a total figure for the year* is fixed after consultation with the Home Grown Timber Advisory Committee—it has been so fixed at twenty-six million cubic feet of hardwoods and seven million cubic feet of softwoods for 1952 exclusive of thinnings below a certain size (6 in. quarter girth), but these figures are appreciably higher than the average thought permissible during the next decade.

Utilization Problems. When imports were cut off, the shortage of timber supplies was such that even poor quality trees were readily saleable at profitable prices. As the situation gradually eases, difficulties are to be expected once more in marketing the lower grades and smaller sizes which will inevitably form the major part of the out-turn for a considerable term of years. Outlets are required for the increasing volume of small thinnings from both State and private forests which are not marketable as pitwood. It has been demonstrated that closer utilization of sawn material is not impossible, but there will remain a good deal for which the pulp mill appears the obvious destination. Unfortunately, *big capital investment is involved, and large volumes* of wood at a relatively low price are necessary to give an economic return. At present there are three such mills in the country, and it is urged that the number should be doubled. Obviously every means of reducing costs of extraction and delivery at the mill needs to be investigated.

Private Forestry. The Dedication scheme under

which the management of privately owned forests will be such that they will make the required contribution to the timber reserves and production of the country, has already been mentioned, but it may be helpful to bring together some of the chief factors affecting the practice of forestry by the private owner. The scheme is applicable to all woods over 150 acres in extent. Skilled supervision must be employed but this does not preclude the owner or his agent if qualified; all reasonable precautions must be taken to protect the woods. A plan of operations, usually for a ten-year period, has to be drawn up in prescribed form, and submitted to the Forestry Commission for approval, and records maintained in prescribed form to permit check of the work actually done against the prescriptions. Grants are then payable on the area planted or regenerated during the year at £14 per acre with a maintenance grant for fifteen years of 4s. 6d. per acre of productive woodland, including the plantations (1952 rates)—partially productive forest being assessed at a proportionately reduced acreage. A licence is required for all fellings exceeding a quarterly allowance of 825 cubic feet and conditions for replanting may be attached, but if the fellings are under an approved plan, the licence is issued without question, whilst if it is refused, compensation for any resultant loss may be claimed. The owner also has the alternative of maintaining simple accounts in prescribed form and receiving repayment of 25 per cent. of the approved net expenditure of the year. Under certain conditions, loans may be made covering a substantial part of the costs of planting, repayment beginning at any time up to the sixteenth year but being completed in all cases by the fiftieth year, with interest at £3 per cent.

The Deed of Covenant is binding on the owner and his successors in title in perpetuity, and only in exceptional circumstances can release be obtained.

A grant of £3. 15s. 0d. per acre is also payable (1952–53) on early thinnings not exceeding a certain size.

Education and Training. Four of the British Universities offer courses leading to a degree in Forestry, viz. Oxford, Edinburgh, Aberdeen, and Bangor. These courses take either three or four years and include a good deal of field work and tours in vacations. Forestry is also included in other courses such as that in Estate Management at Cambridge University, and those given in some of the Agricultural Colleges, e.g. Cirencester. The Forestry Commission maintains five Foresters Schools at the Forest of Dean, Lynford, Benmore, Glentress (Peebles) and Gwydyr (Carnarvon), training men for employment on private estates, etc. as well as for the Commission itself; a period of practical experience is a condition for admission and the course lasts two years. In 1951, 120 men qualified.

Forestry Societies and Associations. The Royal Scottish Forestry Society and the Royal Forestry Society of England and Wales were founded under different designations (as Arboricultural Societies) in 1854 and 1882 respectively and have large memberships including both professionals and many others interested in the subject. They publish quarterly journals. There is a smaller and more exclusively professional Society of Foresters of Great Britain, founded in 1926, and producing the journal *Forestry.*

Mention should also be made of the Empire Forestry Association which publishes the illustrated quarterly *Empire Forestry Review* dealing with all aspects of

forestry in all parts of the Commonwealth including Britain: its membership is composed of both foresters and timber operators and traders. The leading timber organizations in the U.K. are the Timber Trades Federation and the Timber Development Association.

CONCLUSION

In the foregoing chapters, we have reviewed successively the nature and extent of our forests, the ways they influence our conditions of life through their productive and protective roles, the treatment we have meted out to them in the past and the techniques we have gradually developed for their effective protection and better management in our own interests, and we have concluded with a rapid survey of the position in our home country. It is perhaps fitting to conclude with the application of the long term view that has been repeatedly mentioned as an essential part of the equipment of the forest manager and administrator. What developments and changes would we expect to find two or three human generations or a whole forest generation ahead? The driving power behind these changes will clearly be the rapidly increasing pressure on the land generally, primarily for food production but also for production of all essentials for human welfare including wood. A considerable further reduction of the area at present under forest will inevitably take place particularly in the less developed parts of the world, notably in the tropics but also in the more favourable parts of the temperate forest belts. To offset this to some extent, there will have been extensive afforestation such as we are carrying out in this country both of lands that have been mistakenly cleared of forest and of non-forest lands that can now be made to carry trees by advances of knowledge such as modern techniques, use of exotic species, and so on. There will also have been a considerable improvement of the

production per acre through better management and we would be justified in expecting a useful start to have been made towards a further improvement through the selection and breeding of better stock, just as has been done in agriculture which can take advantage of research results so much more quickly.

There should have been some improvement in the distribution of forests in relation to the use of land for the purposes to which it is best suited, and to raising forests where they are most needed for protection of watersheds, agricultural lands and population centres. This development is, however, one that obviously can only take place very slowly.

We should hope to find a much better understanding among the public and their governments of the value of the forests such as already exists in a few countries, e.g. Switzerland, so that a constructive national programme would find general support. This would be associated with greater use of the forests for recreational purposes.

On the question of future demands for wood, there are the strongest grounds for believing that it will long hold its place as a constructional material, and that demands will continue to rise as populations increase and standards of housing, and of living generally, go up. It should be possible to meet these increased demands even from a reduced area of forest because there is still so much room for increased out-turn per acre and reduction of waste, and much of the technical knowledge for doing this is already available. Wood will doubtless be displaced from some of its current uses by alternative materials, mainly the products of chemical industry, but wood technicians have amply demonstrated their ability to develop new techniques

enabling wood to hold its own against many such threats, or to adapt it to new uses to replace the lost ones. There is always the fact that unlike the raw materials of nearly all the substitutes, wood is a self-renewing natural resource and seems destined to be itself a major raw material for chemical industry, starting from the existing large and rapidly growing pulp and paper industry. It is even possible to view wood as a secondary product of forests which must be maintained in any case for the protection of climatic values and above all, water supplies.

BIBLIOGRAPHY

General

No comprehensive survey of forestry as a whole has been attempted in English since W. Schlich's *Manual of Forestry* in five volumes which were published between 1889 and 1908, though further editions of individual volumes appeared up to 1925. The references listed below for Chapter XIV give some general account of the content of the subject from the British viewpoint, whilst *Forests, Forestry and Man* published by the Empire Forestry Association provides a useful general introduction. A number of books have been published more recently, notably by the McGraw-Hill Co. and Chronica Botanica, on several special fields, but tend to be highly technical and most suitable for American use.

The most important current literature is published in the professional journals. Of these, the most authoritative in Britain is *Forestry*, but may be too technical for the general reader who may find the *Quarterly Journal of Forestry* and *Scottish Forestry* (also a quarterly) more helpful. For the timber aspects, the *Timber Trades Journal*, a London weekly, is the chief source. Commonwealth topics are well covered by the quarterly *Empire Forestry Review*, and the monthly *Journal of Forestry* occupies a similar position for N. America. *Unasylva*, published quarterly at Rome by the U.N. Food and Agriculture Organization, should also be seen. *Forestry Abstracts*, appearing quarterly, references world literature with abstracts for all the more important books and articles.

CHAPTER I

Büsgen, M. and Münch, E. (1929). *Structure and life of forest trees*. Chapman & Hall, London. 3rd ed. revised by E. Münch, translated by T. Thomson. An exceptionally useful reference work.

Ridley, H. N. (1930). *The dispersal of plants throughout the world*. Ashford, Kent. Describes the different ways in which seeds, etc. are distributed from the parent plant.

Richards, P. W. (1951). *The tropical rain forest*. Cambridge University Press. A full account of the structure and ecology.

Elwes, H. J. and Henry, A. (1906–13). *Trees of Great Britain and Ireland*. Edinburgh. The standard reference, fully illustrated and documented.

Anon. (1947). *Forests, forestry and man*. Empire Forestry Association, London. A useful presentation of the place of forestry in relation to human welfare.

Sinnott, E. W. and Dunn, L. C. (1950). *Principles of genetics*. McGraw-Hill Co., New York. 4th ed. One of many general textbooks.

Richens, R. H. (1945). *Forest tree breeding and genetics*. Joint Publication No. 8. Commonwealth Agricultural Bureaux. A general review with bibliography.

Lindquist, B. (1948). *Genetics in Swedish forestry practice*. Chronica Botanica Co., Waltham, Mass. A simple account of the position in a country which has taken a leading part in this field.

CHAPTER II

Schimper, A. F. W. (1903). *Plant geography upon a physiological basis*. Translated by W. R. Fisher, revised and edited by P. Groom and I. B. Balfour. The standard work dealing with the whole world. (3rd German edition, 1935.)

RICHARDS, P. W. (1951). *The tropical rain forest.* Cambridge University Press.

CAIN, S. A. (1944). *Foundations of plant geography.* Harper Bros., New York.

JAMES, W. O. (1943). *An introduction to plant physiology.* Oxford University Press. 4th ed.

STILES, W. (1950). *An introduction to the principles of plant physiology.* Methuen, London. 2nd ed.

ROBINSON, G. W. (1949). *Soils: their origin, constitution and classification.* Thomas Murby & Co., London. 3rd ed.

TAMM, G. O. (1950). *Northern coniferous forest soils.* Translation by M. L. Anderson. Scrivener Press, Oxford.

WILDE, S. A. (1946). *Forest soils and forest growth.* Chronica Botanica Co., Waltham, Mass.

CHAPTER III

HENDERSON, F. Y. (1944). *Timber, its properties, pests and preservation.* Crosby Lockwood and Son, London. 2nd ed. A simple general account.

JAY, B. A. (1945). *Timber. An outline of the structure, properties and uses of timber.* Timber Development Association, London. 2nd ed. A brief and simple presentation for the general reader.

WANGAARD, F. F. (1950). *Mechanical properties of wood.* J. Wiley & Sons, New York. A comprehensive and fairly technical review.

BROWN, N. C. (1950). *Forest products: harvesting, processing and marketing of materials other than lumber.* J. Wiley & Sons, New York. Primarily referring to N. American conditions but with much of general application.

CHAPTER IV

TANSLEY, A. G. (1939). *The British Isles and their vegetation.* Cambridge University Press. A comprehensive survey from the ecological viewpoint.

STEBBING, E. P. (1922–6). *The forests of India.* J. Lane, The Bodley Head, London. 3 vols. Primarily a historical account of the administration.

CHAPTER V

KITTREDGE, J. (1948). *Forest influences.* McGraw-Hill Co., New York. A standard, well documented reference book.

BENNETT, H. H. (1939). *Soil conservation.* McGraw-Hill Co., New York. A detailed description of soil erosion and conservation methods.

ANON. (1948). *Soil conservation, an international study.* Food and Agricultural Organization, Washington. A brief illustrated survey of the world situation.

HUGHES, J. F. (1950). *The influence of forests on climate and water supply.* Commonwealth Agricultural Bureaux, London. (Reprint.) A critical review with bibliography.

CHAPTER VI

CHRYSTAL, R. N. (1948). *Insects of the British woodlands.* F. Warne & Co., London. Primarily for the student.

BEESON, C. F. C. (1941). *The ecology and control of the forest insects of India and the neighbouring countries.* Published privately, Dehra Dun, U.P. New edition in preparation at the Forest Research Institute, Dehra Dun. A standard work of general as well as local application.

BOYCE, J. S. (1948). *Forest pathology.* McGraw-Hill Co., New York. 2nd ed.

BAWDEN, F. C. (1950). *Plant viruses and virus diseases.* Chronica Botanica Co., Waltham, Mass. 3rd ed.

ANON. (1950). *Chestnut blight.* Forestry Commission Booklet No. 3. London.

CHAPTER VII

SISAM, J. W. B. (1947). *The use of aerial survey in agriculture and forestry.* Joint Publication No. 9. Commonwealth Agricultural Bureaux. A concise account of methods and application.

BROWN, N. C. (1949). *Logging: the principles and methods of harvesting timber in the United States and Canada.* J. Wiley & Sons, New York.

HARRIS, P. (1946, reprinted 1950). *A handbook of woodcutting.* H.M. Stationery Office, London. (Forest Products Research Laboratory.) Summarizes the principles and methods.

SIMONS, E. N. (1946). *Saws and sawing machinery.* Sir Isaac Pitman and Sons, London.

BROWN, N. C. (1947, reprinted 1948). *Lumber: manufacturing, conditioning, grading, distribution and use.* J. Wiley & Sons, New York. A useful survey from the general standpoint.

ANON. (1946). *Timber seasoning.* Timber Development Association, London. A brief summary of the essential features.

CARTWRIGHT, K. ST. G. and FINDLAY, W. P. K. (1946). *Decay of timber and its prevention.* (Forest Products Research Laboratory.) H.M. Stationery Office, London. Deals with wood-rotting fungi.

ANON. (1950). *Marine borers and methods of preserving timber against their attack.* Forest Products Research Laboratory Leaflet No. 46. H.M. Stationery Office, London.

MacGregor, W. D. (1950). *The protection of buildings and timber against termites.* Forest Products Research Laboratory Bulletin No. 24. H.M. Stationery Office, London.

Anon. (1946). *Timber preservation.* Timber Development Association, London. A concise summary of methods in non-technical terms.

Wood, A. D. and Linn, T. G. (1942). *Plywoods: their development, manufacture and application.* W. & A. K. Johnston, Edinburgh.

Grant, J. (1947). *Wood pulp.* Chronica Botanica Co., Waltham, Mass. 2nd ed.

Edlin, H. L. (1949). *Woodland crafts in Britain.* B. T. Batsford, Ltd., London.

Anon. (1948). *The fireproofing of timber.* Timber Development Association, London.

CHAPTER VIII

Toumey, J. W. and Korstian, C. F. (1947). *Foundations of silviculture.* J. Wiley & Sons, New York. 2nd ed. revised. Primarily for N. American conditions but applicable to temperate regions generally.

Troup, R. S. (1952). *Silvicultural systems.* Oxford University Press. 2nd ed. A standard well illustrated textbook.

Champion, H. G. and Griffith, A. (1948). *Manual of general silviculture for India.* Oxford University Press, Calcutta. Refers generally to tropical conditions.

CHAPTER IX

Anon. (1951). *Forestry practice.* Forestry Commission Bulletin No. 14. 5th ed. London.

Anon. (1947). *The establishment of hardwoods.* Forest Operations Series No. 2. Forestry Commission, London. A brief account of nursery and plantation treatment.

SHEAT, W. G. (1948). *Propagation of trees, shrubs and conifers.* Macmillan & Co., London. Useful for propagation by cuttings, etc.

PEACE, T. R. (1952). *Poplars.* Forestry Commission Bulletin No. 19. London. Gives a full account of planting techniques, etc., well illustrated.

CHAPTER X

TROUP, R. S. (1952). *Silvicultural systems.* Oxford University Press. 2nd ed.

ANON. (1928). *Growth and yield of conifers in Great Britain.* Forestry Commission Bulletin No. 10. Gives statistical data for the chief species.

ANON. *Revised yield tables for Japanese larch in Great Britain.* Forestry Commission, London.

ANON. (1951). *The thinning of plantations.* Forest Operation Series, No. 1. 2nd ed. Forestry Commission, London.

CHAPTER XI

BRUCE, D. and SCHUMACHER, F. X. (1942). *Forest mensuration.* McGraw-Hill Co., New York. 2nd ed. The most generally used reference work.

JERRAM, M. R. K. (1939, reprinted 1950). *Elementary forest mensuration.* Thomas Murby & Co., London. Adequate for most purposes in Britain.

SISAM, J. W. B. (1947). *The use of aerial survey in agriculture and forestry.* Joint Publication No. 9. Commonwealth Agricultural Bureaux.

SPURR, S. H. (1948). *Aerial photographs in forestry.* The Ronald Press Co., New York. Describes techniques for deriving statistical data for trees and crops.

BRASNETT, N. V. (1953). *Planned management of forests.* George Allen & Unwin, Ltd., London.

KNUCHEL, H. (1946). *Management control in selection forest.* Commonwealth Forestry Bureau Technical Communication No. 5. Refers primarily to Swiss forests.

HUMMEL, F. C. *et al.* (1952). Forest Records No. 5. *General Volume Tables for Oak*: No. 6, ditto *Beech*, No. 7, ditto *Birch*, No. 8, ditto *Scots pine*, No. 9, ditto *European larch*, No. 10, ditto *Norway spruce*, No. 11, ditto *Corsican pine.* Forestry Commission, London.

HILEY, W. E. (1930). *The economics of forestry.* Oxford University Press. The only comprehensive work in English.

CHAPTER XII

ANDERSON, M. L. (1950). *Selection of tree species for British and Irish conditions.* Oliver & Boyd, Edinburgh.

ANON. (1951). *Forestry Practice.* Forestry Commission Bulletin No. 14. London.

CHAPTER XIII

ANDERSON, M. L. (1949). *State control of private forestry under European democracies.* Oxford Forestry Memoirs No. 22. Department of Forestry, Oxford. Gives an account of the legislation, etc. in each country.

GORDON, W. A. (In preparation). *The law of forestry.* A general account with detail for the United Kingdom and the Colonies.

TROUP, R. S. (1940). *Colonial forest administration.* Oxford University Press, Calcutta. A general review of the problems with details for each colony.

KISSIN, I. (1944). *Co-operation in forestry.* Commonwealth Forestry Bureau Technical Communication No. 2. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, Bucks. A short survey with bibliography.

KISSIN, I. (1945). *Forestry credit.* Commonwealth Forestry Bureau Technical Communication No. 3. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, Bucks. A short survey with bibliography.

ANON. *Forestry Acts* 1919, 1945, 1951. H.M. Stationery Office.

ANON. (1950). *Dedication of woodlands.* Booklet No. 2. 2nd ed. Forestry Commission, London.

CHAPTER XIV

ACKERS, C. P. (1947). *Practical British forestry.* Oxford University Press. 2nd ed. With particular reference to the private estate.

TAYLOR, W. L. (1945). *Forests and forestry.* Crosby Lockwood & Son Ltd. A general account for the non-technical reader.

EDLIN, H. L. (1947). *Forestry and woodland life.* B. T. Batsford Ltd. A popular account.

EDLIN, H. L. (1953). *The Forester's Handbook.* Thames & Hudson, London.

ROWE, W. H. (1947). *Our forests.* Faber & Faber Ltd., London.

ANON. (1952). *Census of woodlands.* Record No. 3, 1947–49. Forestry Commission, London.

MACGREGOR, J. J. (1949). *The forest economy of three private estates in Great Britain.* Institute Paper No. 25. Department of Forestry, Oxford.

FORESTRY COMMISSION. *Reports on post-war policy.* Cmd. 6447 and 6500. H.M. Stationery Office.

FORESTRY COMMISSION. *Annual Report of the Forestry Commission.* H.M. Stationery Office.

INDEX

Acland Report, 196
Advisory committees, Regional, 201
Afforestation, 177
Age, 12
Agriculture combined with forestry, 142
Agriculture, Value of forest to, 69
Alcohol from wood, 42
Alder, 21
Animal haulage, 103
Animals, Harmful, 82
Arbor days, 193
Area under forest, 6
Ash, 40, 113, 126, 128, 207
Aspen, 111

Bacterial diseases, 89
Baobab, 11, 12
Bamboos, 15, 41
Bark beetles, 84
Bark per cent., 159
Beech, 8, 15, 17, 20, 22, 23, 94, 109, 112, 123
Biological control, 87
Biological influences, 7
Birch, 15, 40, 111, 145
Blister rust, 89
Bole form, 9
Breeding, 25
Burning, Early, 79
Burning, Effect on vegetation, 35

Canopy layers, 28
Cedar, 12
Cellulose, 41
Census, 101
Chalkland, Afforestation of, 204
Chestnut, 11, 113, 126
Chestnut blight, 57, 88
Choice of species, 137
Classification of forests, 33
Classification of trees, 147
Cleaning, 144
Clear felling, 120
Clearing of forest, 50
Cleft wood, 113
Climax forest, 31
Climbers, 9, 27, 152
Compartments, 163
Compartment history (register), 167
Competition, 29
Control of fellings (U.K.), 207
Consumption of wood, 47
Control of prescriptions, 166
Cooperage, 113
Co-operation, 190
Coppice, 72, 125, 153
Coppice with standards, 125, 153
Cork, 116
Creosoting, 108
Cruising, 100
Cultural operations, 152
Cuttings, 142

Deciduous habit, 23
Dedication Scheme (U.K.), 208
Definitions, 1, 2, 5
Derelict woodlands, 206
Diseases of trees, 57
Distillation, 115
Distribution, Geographical, 3
Dominance, 147

Douglas fir, 8, 48, 93, 109, 207
Draining effect, 177, 179
Drought, 96
Dyes, 44

Ecology, 118
Economic crops, 53
Economics of forestry, 168
Education, 193, 210
Elm, 40, 72, 88
Employment, 117
Epiphytes, 28
Erosion, 60
Eucalyptus, 8, 11, 142
Evergreen habit, 23
Exotic plantations, 175
Expenditure on forestry, 169

Felling Series, 163
Fencing, 83
Fibreboard, 114
Fibrous materials, 43
Financial forecast, 166
Fire protection, 76
Fire tolerance, 73
Fireproofing timber, 109
Fires, 52, 74, 79
Floating, 101
Floods, 63
Flowering, 13
Flowering, Gregarious, 15
Fodder, 45
Food from the forest, 43
Food from wood, 42
Forestry Act 1919, 197
Forestry Act 1945, 199
Forestry Act 1951, 208
Forestry Fund, 197
Form factor, 158
Frost damage, 95
Frost lift, 96
Frost split, 96
Fruiting, 14
Fuel woods, 40, 47
Fungus damage, 88, 91
Furniture, 112

Genetics, 24
Germination, 18
Girdling, 152
Girth records, 10
Glazed frost, 94
Grafting, 135
Grants for forestry (U.K.), 209
Grazing, 51, 81
Grazing, Resistance to, 73
Group regeneration, 121
Group selection system, 154
Growing stock, Normal, 165
Gully plugging, 181
Gums, 44

Hardiness, 74
Hardwood forests of U.K., 205
Heartwood, 10
Heathland, Afforestation of, 175, 202
Hedges, 132
Height, 8
History of U.K. forests, 195
Hornbeam, 124
Human influences, 34
Humus, 68
Hybrids, 14, 25

Improvement fellings, 152
Inaccessibility, 71
Increment, 156
Income from forestry, 169
Indicators, 137
Industries, 105
Insect damage, 55, 83, 144
Insecticides, 86
Insurance against fire, 79
Irrigated plantations, 180

Kauri, 12

Labour, 117
Laminated wood, 111

Larch, 25, 94, 134
Law, Forest, 191
Light requirements, 22
Lightning, 75, 93
Lignin, 42
Lining out, 133
Loans, 209

Magnolia, 13
Malaria, 57
Management, Forest, 161
Mangroves, 10, 17
Mapping, 100
Markets, 54
Matchwood, 111
Medicinal products, 43
Mesquite, 179
Mineral requirements, 20
Mining timber, 56, 202
Mixture of species, 121, 138
Motor transport, 104
Multiple use of forest land, 187
Mycorrhiza, 22

Nature reserves, 70
Netting, 144
New Forest, 2, 81, 197
Normal forest, 164
Nurseries, 130
Nurseries, Temporary, 136

Oak, 8, 11, 12, 14, 17, 18, 44, 84, 96, 113, 123
Ownership, 188

Paper, 41
Pinus radiata, 21, 175
Pine, Lodgepole, 73
Pine, Scots, 8, 11, 12, 14, 20, 25, 83, 84, 91
Pine, Weymouth, 89
Pitwood, 56, 202
Plan of operations, 165, 168
Planting board, 133
Planting out, 139
Ploughing, 203
Plywood, 109
Pollination, 13
Poplars, 25, 89, 135, 136, 200
Preservation, Wood, 108
Profitableness of forestry, 170
Policy, Forest, 183
Price of timber, 168
Private forestry (U.K.), 208
Pruning, 150

Quality class, 158
Quartergirth measurement, 159

Rabbits, 144, 206
Rainfall, 59
Ravine afforestation, 182
Rayon, 42
Reclamation, 173
Reclamation of eroded land, 181
Regeneration, Artificial, 127
Regeneration, Natural, 118
Regulation of fellings, 81
Research, 192
Research in U.K. 201
Reservation of forests, 97
Resin, 44, 116, 177
Revenue from forestry, 171
Rights, 98
Roads, 103
Robinson Report, 199
Root length, 20
Root nodules, 21
Root suckers, 72
Ropeways, 102
Rotation (age), 157, 164
Rotation, Financial, 170
Rubber, 44

Saline soils, 180
Sample plots, 157
Sand dunes, 67, 176
Sapwood, 10

Sawmilling, 105
Seasoning, 106
Season for planting, 138
Seed collection, 127
Seed crops, 14, 19
Seed dispersal, 15
Seed longevity, 18
Seedling establishment, 19
Selection coppice, 153
Selection felling, 124, 153
Sequoia gigantea, 8, 11
Settlement of forests, 97
Shelterbelts, 67, 176
Shelterwood, 120
Shortages, 172
Silting, 64
Silver fir, 8, 95, 125
Silviculture, 118
Silvicultural systems, 152
Site class, 158
Site preparation, 129, 136
Skidding, 104
Smoke damage, 56
Snow damage, 94
Societies (U.K.), 210
Sowing, 129, 132
Spacing in plantations, 136
Spruce, Norway, 95, 125, 204
Spruce, Sitka, 204
Squirrel damage, 83, 206
Standards, Coppice with, 126, 153
State control, 189
Stem analysis, 160
Stock maps, 101, 162
Storage of seed, 128
Stratification, 128
Strip regeneration, 121
Structure of forests, 26
Stump analysis, 160
Stump planting, 141
Sugar from wood, 42
Superstitions, 72
Survey of resources, 100
Swamp afforestation, 178
Sycamore, 40, 113

Tannin, 44, 116
Taungya, 142
Taxodium, 24
Teak, 12, 66, 84, 101, 141, 142, 171
Temperatures, 69
Tending, 146
Tending irregular crops, 150
Termites, 86
Thinning cycle, 149
Thinnings, 146
Timber consumption, 47
Timber properties, 38
Training, 210
Transpiration, 65
Transplanting, 133
Tsetse flies, 57
Turnery, 112

Unisexual trees, 13

Vegetative propagation, 135
Veneers, 109
Vermin, numbers destroyed, 206
Virus diseases, 86, 90
Volume, Tree, 11
Volume tables, 159

Water requirements, 19, 65
Wattles, 175
Weeding, 135, 143
Wild animals, Protection against, 82, 144
Wind damage, 92
Wind erosion, 66
Wolf trees, 148
Wood pulp, 41, 113
Working Circles, 163
Working Plans, 161
Working Scheme, 168

Yield, Intermediate, 150
Yield, Sustained, 164
Yield Tables, 158
Yield Tables, Money, 170